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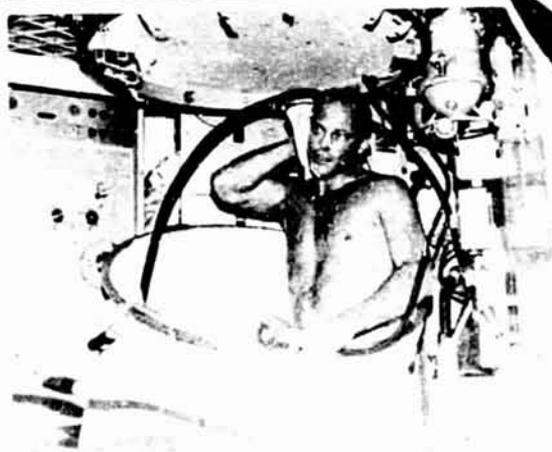
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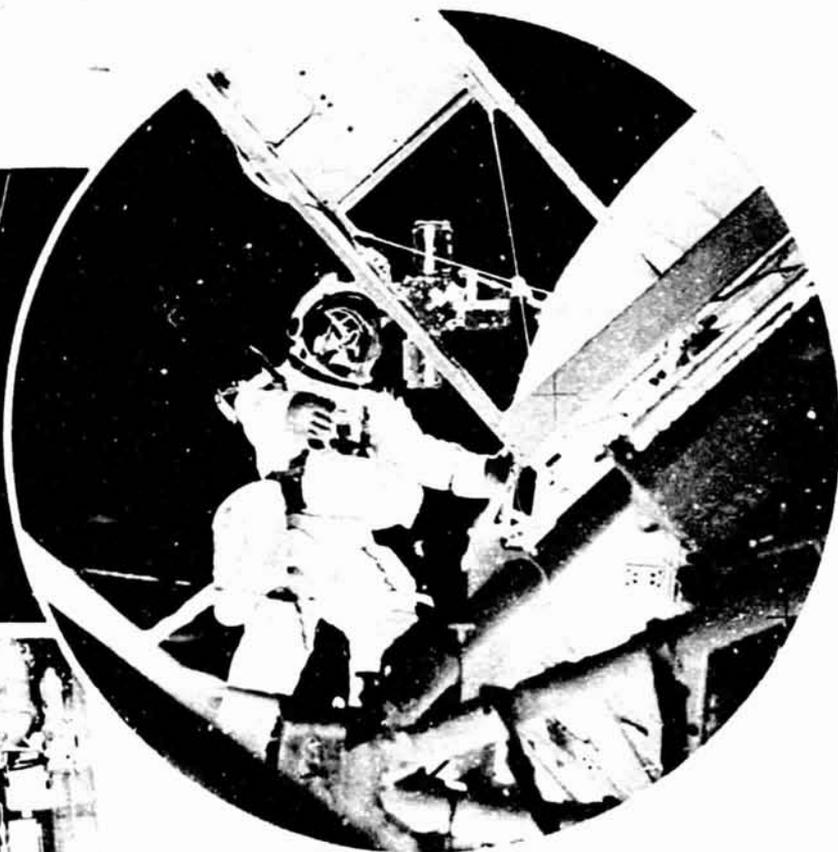
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16. ABSTRACT  The Skylab's Saturn Workshop mission performance is presented. The Saturn Workshop circled the Earth every 93 minutes at approximately 435 kilometers altitude with its orbit inclined 50 degrees from the Equator. It was manned by 3 different crews for 171 of the 272 days covered by this report. A variety of experiments were conducted to determine man's ability to live and work in space for extended periods, to make Sun and Earth investigations, and to advance science and technology in several areas of space applications. Performance is compared with design parameters, and problem causes and solutions are treated. The Saturn Workshop successfully performed its role and advanced the technology of space systems design.					
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**"... an affirmation that man can live  
and do very useful work in space".**

**...William C. Schneider**



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## SECTION 1

### INTRODUCTION

The use of space is already affecting the lives of most of the peoples of the world, directly or indirectly. Space, because of its unique vantage point for observations, vacuum, and nullified gravity effect, offers potential applications impossible to achieve on Earth. The first United States manned flights into space, taken only a few years ago, were directed toward demonstrating the feasibility of space flight. Mercury and Gemini program flights were made primarily to evaluate, in successively longer flights, the ability of men to live and work safely in space. The next manned space program, Apollo, culminated in six successful landings on the Moon, and demonstrated that the direct involvement of man in space flight was of inestimable value in the performance of experiments, observation of new phenomena, and operation of the spacecraft.

The Skylab program (ref. 1) was a logical continuation in the manned exploration of space and the development of space applications. The Apollo program had left some important questions unanswered. The long-range physiological and psychological effects of weightlessness on man were unknown. Nor was it known if man could perform varied and complex tasks for an extended time in space. There was also interest in whether the vacuum and zero gravity could be used to realize economic returns. To answer these and many other questions, the Apollo Applications program, later renamed the Skylab program, was instituted. A number of proven flight designs, along with existing ground facilities, launch vehicles, and other hardware left from the Apollo program, were to be used.

This program led to the design of the Saturn Workshop, which together with the command and service module made up the Skylab vehicle, the first United States space laboratory. Its capabilities derived, not from a major technological breakthrough, but from a combination of existing components and new designs. Unlike our previous manned spacecraft, the Saturn Workshop contained a habitable volume large enough to allow the crew to move about freely and a source of power which was not limited by an expendable supply of fuel.

Five major objectives evolved for Skylab: to determine man's ability to live and work in space for extended periods, to determine and evaluate man's aptitudes and physiological responses to space and his adaptation after returning to Earth, to advance techniques of solar astronomy beyond the limits of Earth-based observations, to develop improved techniques for surveying Earth resources from space, and to add to knowledge in other scientific and technological fields. The Saturn Workshop was designed to support these objectives.

The launch vehicle provided the payload capability for inserting into Earth orbit the facilities, equipment, and instruments required to conduct an extensive experiment program. The number and variety of these experiments greatly exceeded those of any previous flight. Designed to satisfy the stated program objectives, the experiments fell into several broad categories. One was a group of biological

and medical experiments to provide data on the physiological reactions of the crews to prolonged exposure to the space environment. There were several groups of experiments concerned with science, technology, and space applications. These included observations of the Sun and sky, observations of the surface of the Earth, and the application of weightlessness and vacuum. Later, some experiments developed by high school students were incorporated into the scheduled program and several science demonstrations were introduced.

On May 14, 1973, the Skylab mission began with the launch of the Saturn Workshop into a nearly circular orbit at an altitude of approximately 435 kilometers and at an inclination of 50 degrees from the Earth's Equator. This altitude was high enough above the Earth's atmosphere to eliminate optical interference and excessive aerodynamic drag, yet low enough to allow a large payload and high orbit inclination within the performance capability of the launch vehicle. The area of view at 50 degrees inclination included most of the populated and food-producing areas of the Earth.

The mission lasted 272 days, during which time nine men in three different three-man crews manned the Skylab for periods of 28, 59, and 84 days. Despite some problems, the total time which the crews spent onboard the Skylab substantially exceeded that which had been planned. Furthermore, the crews performed both scheduled and unscheduled operations with less difficulty than had been anticipated.

The achievements of the Skylab program greatly surpassed expectations. One measure of success of the program is a comparison of actual and planned performance of experiments. Goals were exceeded by a significant percentage in most experiment categories: biomedical--32 percent; solar physics--27.5 percent; Earth observations--60 percent; astrophysics--105 percent; engineering, technology and space manufacturing--10 percent; and student investigations--18 percent. The extent of the work accomplished by the crews in the conduct of experiments demonstrated man's ability to accomplish useful and meaningful work in space. The extent of the repairs, far beyond that envisioned before flight, and the alternative operational modes that were developed during the mission to counteract problems demonstrated anew the value of man in certain space missions.

The success of the Skylab mission means that the foundation for future orbital stations has been significantly enhanced. Except for food production and the recycling of wastes, few advances beyond present space technology should be required for extremely long missions. For shorter missions, the vast aggregation of flight-proven hardware can contribute greatly to a useful inventory of standardized, low-cost space components and systems for both manned and unmanned programs. The procedures used in design, development, simulation, and operation of Skylab, with minor modifications, are also applicable to future programs.

This report contains the major results of the Saturn Workshop evaluation that was accomplished to support the mission and to determine performance in detail. This evaluation contributed to the success of the mission and the safety of the crew through determination of anomalous performance and system trends, thereby permitting real-time actions to solve or compensate for problems. The report also contains a brief description of the Saturn Workshop configuration, a summary of the mission and operations, and brief descriptions of the various systems. Performance of major systems of the Saturn Workshop are reported in separate sections. The report is based primarily on the systems technical reports (ref. 2 through 12).

This report is limited to the Saturn Workshop, and to those experiments that were the responsibility of the Marshall Space Flight Center. It also includes the evaluation of integration into the Saturn Workshop of hardware or experiments developed by others. The evaluations of the launch vehicle and launch, by Marshall Space Flight Center and Kennedy Space Center, are covered in references 13 and 14. Crew performances and hardware and experiments developed by Johnson Space Center are reported in references 15 through 17. Other information concerning Skylab can be found in references 18 through 50. The reference list does not include experiment reports, which will be issued in the future.

This report has been prepared to serve as a useful reference to those involved in future space applications as well as those who were involved in the design, development, operation, or utilization of Skylab. It is intended for general application and as a guide to areas of specific interest. Because of the broad range of subject matter, the depth of technical discussion has been restricted to that necessary to give a general understanding of each major topic. General terminology has been used in lieu of certain technical or specific nomenclature used during the Skylab program. Units used in the design of the Saturn Workshop have been used in this report, resulting in some mixture between English units and those of the International System of Units. Time in days is referenced to the launch of the Saturn Workshop on Day 1, and daily time is given in Greenwich mean time.

## SECTION 2 CONFIGURATION

This section presents some pertinent background information that affected the Saturn Workshop's configuration and an overall description of that configuration. It is a guide to the vehicle's general arrangement and size and, to a small degree, explains how it developed.

Many factors influenced the design, and an important one, economics, led to an early decision to use hardware, where possible, that had been developed for other programs, especially the Apollo lunar program. This resulted first in a concept for the conversion in orbit of an existing launch vehicle stage into a habitable workshop. In this concept, the second stage of a manned Saturn IB launch vehicle would have a dual function. After reaching orbit, the second stage hydrogen tank would be drained of residual fuel and vented. The crew would then transfer to the hydrogen tank and convert it into living quarters and a workshop. The structural components not affected by hydrogen would be installed before launch, but the crew would have to transfer all food, supplies, lighting, and other equipment from their stowage locations to the tank. This concept later became known as the "wet workshop."

An airlock was required between the Apollo command module and the workshop to give the crew a means of egress to space for extravehicular activities. In addition, the airlock structure would provide a place for external stowage of pressure-gas bottles and other hardware. After achieving orbit, the command service module would dock to the airlock, and the crew would outfit the workshop.

During the Saturn Workshop conceptual design period, several independently launched experiment payloads were under development or consideration, as well as resupply vehicles to extend mission durations. One experiment payload, a solar observatory, was to be launched on a Saturn IB. It would have the necessary systems to operate independently in orbit and could dock with a separately launched command and service module. When it became obvious that there were advantages in combining the workshop and experiment missions, a docking adapter with multiple docking ports was added to the workshop concept to permit docking of the various payloads, including the solar observatory.

Hardware procurement was begun. However, after the first lunar landing, a Saturn V launch vehicle became available from the Apollo lunar program. Since this vehicle using only two of its three stages could place several times as great a payload in orbit as the Saturn IB, the Saturn V third stage (the same as the Saturn IB second stage) could be modified and fully equipped before launch. The "dry workshop" concept had many advantages, such as the capability for complete prelaunch checkout of hardware and systems, more time for crews to conduct useful work in orbit in lieu of transferring and installing equipment, and integration into one payload of most of the experiments previously planned for separate launches. It would allow a larger control center for operating the solar observatory and longer periods of operation. Moreover, the solar observatory's independent communication, electrical, and attitude control systems would provide the dry workshop with additional and in some respects dual capabilities in these

systems. Since the experiment payloads would no longer be launched separately, the docking adapter ports were reduced to two, one for normal use and one for rescue capability.

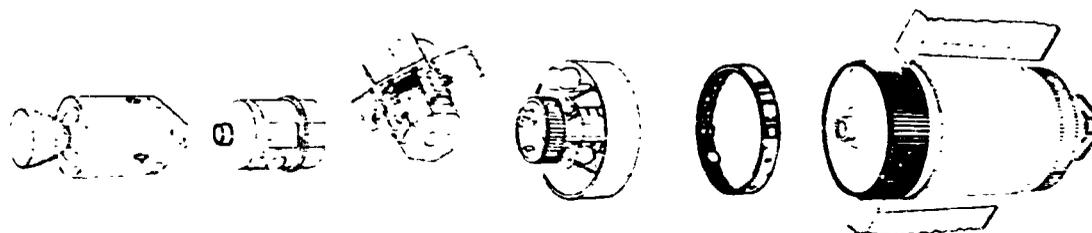
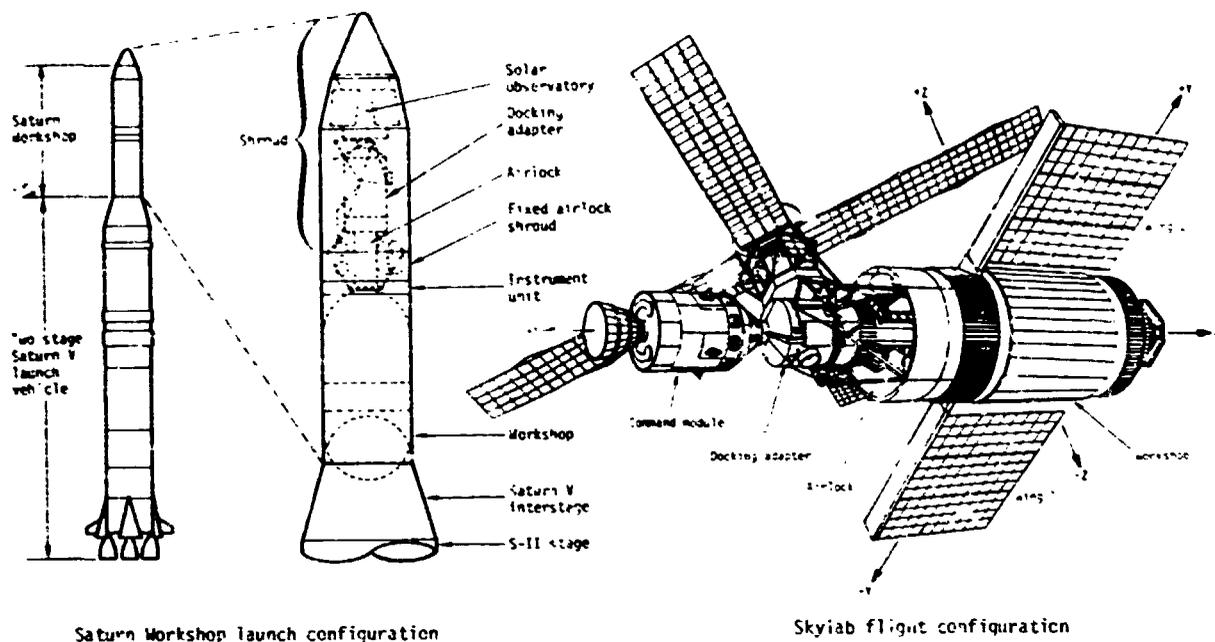
Major design changes required to convert the launch stage into a dry workshop included elimination of the engines and other flight hardware, installation of experiment hardware and life support systems, and stowage of consumables (food, water, and so forth). The command and service module carrying the crew had to be launched separately since the dry workshop would have no flight testing to permit manrating it.

Thus, economic factors, including the use of previously developed Apollo and Gemini hardware and the retention of hardware started for the wet workshop, had a major influence on the conceptual development and final design of the Saturn Workshop. When launched, it contained all the elements needed to sustain the crew and operations. Food and water are stored on board and the necessary hardware is provided for collection and disposal of human wastes. There are provisions for supplying a breathable atmosphere and controlling temperature, pressure, and humidity. Electrical power is produced by direct conversion of solar energy, using two sets of solar arrays, one mounted on the workshop and the other on the solar observatory. The necessary system sensors, controls, and communications devices are included so that decisions can be made and implemented either by the crew or ground controllers. Means of controlling precisely the orientation of the Saturn Workshop are provided to facilitate the generation of required electrical power and the efficient collection of experiment data.

The Saturn Workshop far exceeds in size and complexity any previous spacecraft. It is a cluster of four separately manufactured modules and, when assembled in its flight configuration, is 86 feet long and weighs 195,000 pounds. The modules are designated, according to their functions, the docking adapter, airlock, workshop, and solar observatory. Figure 2-1 identifies the individual modules and shows the designed configuration. The instrument unit, shown as part of the Saturn Workshop, is a functional part of the launch vehicle and becomes inactive after the Saturn Workshop is initially activated. An aerodynamic shroud covers the solar observatory, docking adapter, and airlock during launch, and is ejected after orbital insertion. Next, the solar observatory is rotated 90 degrees from its launch position, clearing the primary (axial) port for command and service module docking. The solar arrays and other components are then deployed to put the Saturn Workshop in its orbital configuration.

This report covers performance of the integrated systems of the Saturn Workshop; however, module nomenclature is used where necessary to identify the location of components or systems. Figure 2-2 is a cutaway view of these modules. When the command and service module is docked, the habitable volume of the Skylab is within the command module, docking adapter, airlock, and workshop. Certain components or systems are identified primarily with the Saturn Workshop's habitable volume (the docking adapter, airlock, and workshop), and, for convenience, these three modules are collectively referred to in this report as the laboratory.

Docking of the command module and transfer of personnel and equipment is normally through the axial port of the docking adapter, but there is a backup or rescue port on the -Z axis. The docking adapter, 10 feet in diameter and 17 feet long, is the control center for the various solar, Earth observation, and metals and materials processing experiments. The equipment for the numerous experiments associated with each of these is located near their controls. The docking adapter



Module name (report)	Saturn Workshop					
	Command and service module	Docking adapter	Solar observatory	Airlock	Instrument unit	Workshop
Module name (development)	Command and service module	Multiple docking adapter	Hubble telescope mount	Airlock module and airlock shroud	Instrument unit	Orbital workshop
Function	Crew ascent & descent	Docking interface Experiment controls & displays Earth observation Stowage	Solar observation Power source Attitude control	Power control & distribution Environmental control Data center Extravehicular activity hatch Caution and warning	Launch vehicle control Saturn workshop activation	Primary living & working area Experiment laboratory Power source Stowage
Length (ft)	34.3	17.3	13.3	17.6	3.0	46.1
Diameter (ft)	13.0	10.0	11.0	10.0/5.5/22.0	22.0	22.0
Working volume (cu ft)	210	1,140	-	624	-	10,426

Figure 2-1.- Design configuration.

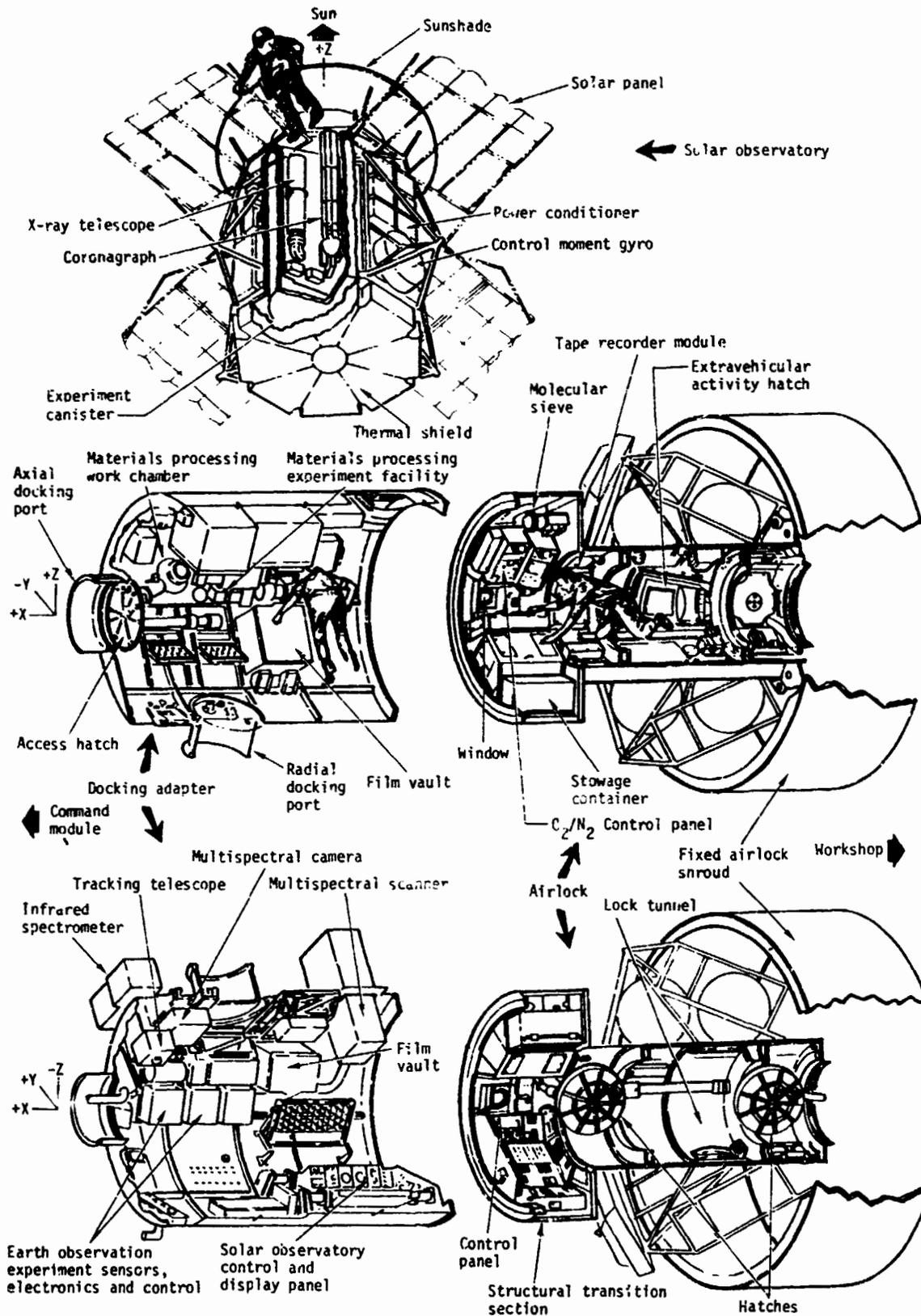


Figure 2-2.- Cutaway view of modules and launch configuration.

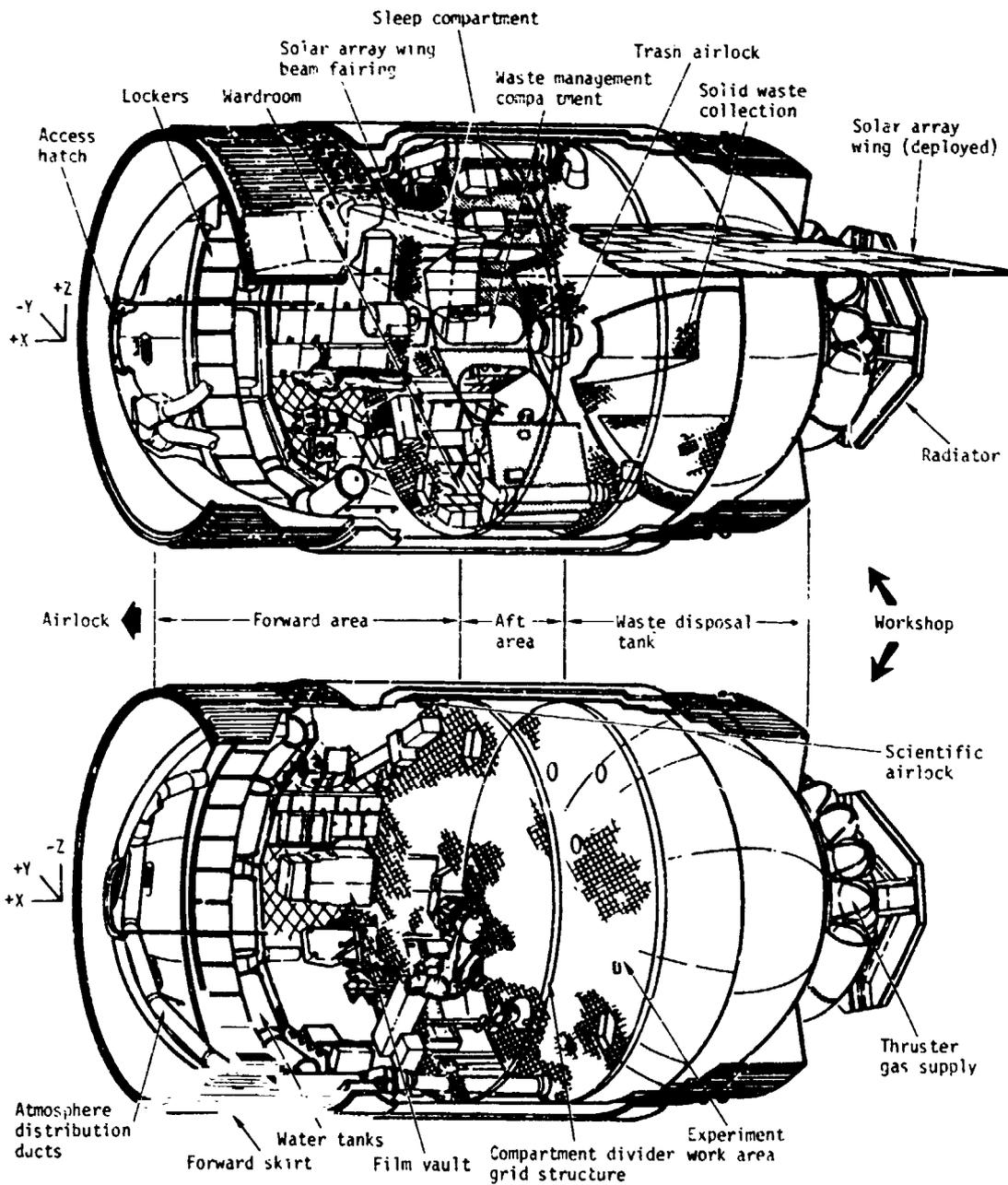
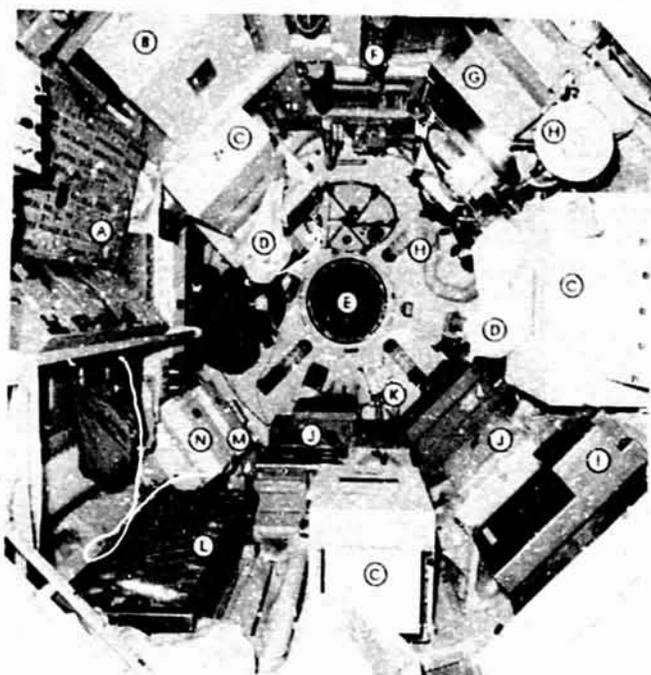


Figure 2-2.- (Continued)

also provides stowage for the experiments and other equipment. Figure 2-3 is a photograph of the docking adapter looking forward toward the command module hatch, and shows the radial arrangement.



- A. Solar observatory control console
- B. Stowage container
- C. Film vaults
- D. Disposal bags
- E. Axial docking port hatch
- F. General illumination lights
- G. Experiment equipment stowage container
- H. Ventilation fan diffusers
- I. Earth observation experiment equipment
- J. Earth observation tape recorders
- K. Speaker intercom assembly
- L. Foot restraint platform
- M. Video tape recorder transport
- N. Video tape recorder electronics

Figure 2-3.- Docking adapter looking forward toward command module hatch.

Figure 2-4 is a view looking aft from the docking adapter into the airlock. The forward end of the airlock is the same diameter as the docking adapter and mates directly to it. This part is 7 feet long and is referred to in this report as the structural transition section. It contains the electrical power and other

- A. Film return container storage rack
- B. Materials processing equipment
- C. Molecular sieves
- D. Airlock hatch
- E. General illumination lights
- F. Disposal bags
- G. Flight data file
- H. Airlock control and display panel
- I. Video tape recorder electronics
- J. Foot restraint platform
- K. Earth observation tape recorders
- L. Film vaults
- M. Experiment equipment storage container

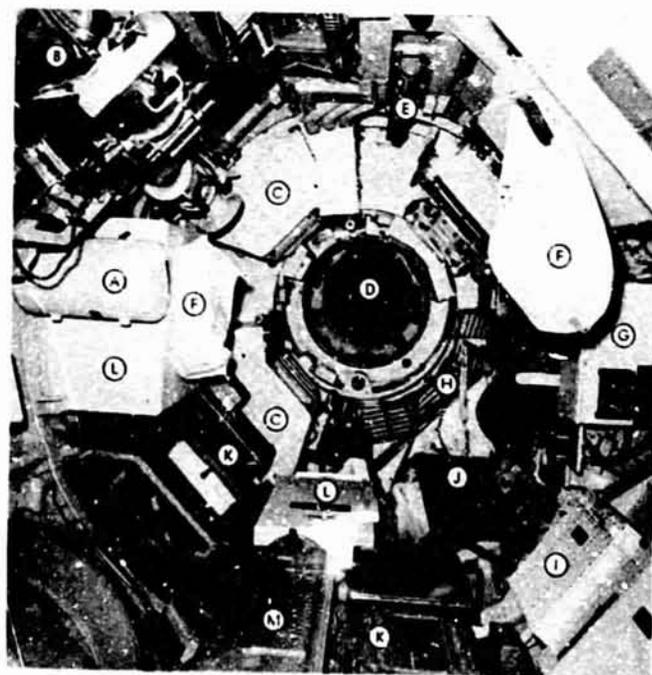
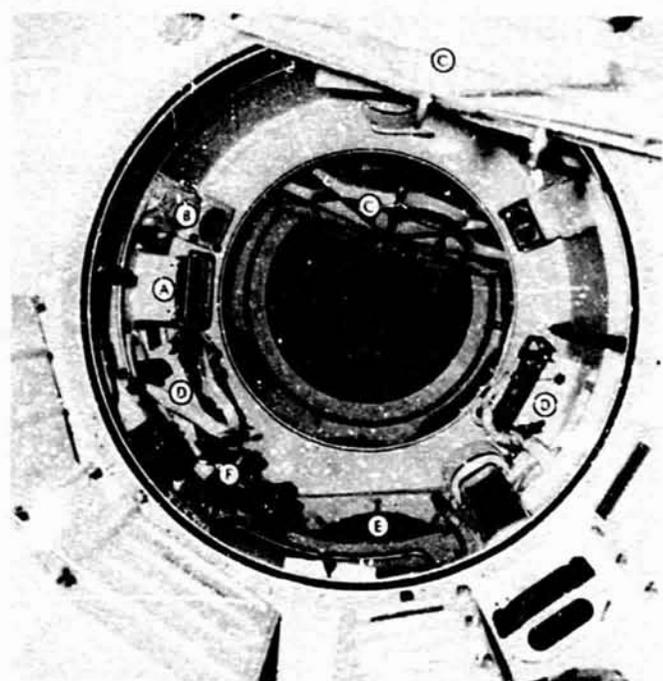


Figure 2-4.- Docking adapter looking aft toward the airlock hatch.

control panels, and much of the laboratory atmosphere support equipment. The control panels and other equipment are mounted radially. The hatch leads aft into the lock tunnel which is 5.5 feet in diameter and 15 feet long (fig. 2-5). It has a hatch on each end to seal it off from the laboratory so that the extravehicular hatch on the cylinder wall can be opened to give the crewmen egress to space. A view from outside looking into the lock compartment through the extravehicular hatch is shown in figure 2-6. The lock compartment contains the necessary equipment for the extravehicular activity and some other equipment and stowage.



- A. Life support umbilical control panel
- B. Lock light assemblies
- C. Lock hatches
- D. Extravehicular control panels
- E. Extravehicular hatch
- F. Lock depressurization valve

Figure 2-5.- Looking aft into the airlock lock compartment.

- A. Lock
- B. Extravehicular hatch
- C. Handrails
- D. Insulation material
- E. Lock hatch

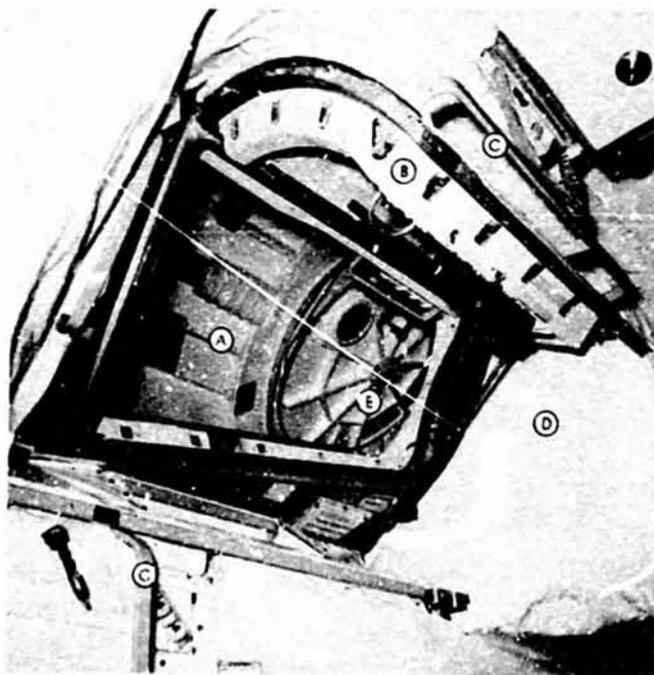


Figure 2-6.- Extravehicular hatch looking into the airlock lock compartment.

The hatch at the aft end of the airlock leads into the workshop, which has a habitable volume 22 feet in diameter and 27 feet long. The forward part, shown in figure 2-7, is a large experiment area with several experiments and other equipment. It also contains the cylindrical water tanks and numerous lockers and

- |                                      |                                  |
|--------------------------------------|----------------------------------|
| A. Food storage containers           | G. General illumination lights   |
| B. Stowage containers (ring lockers) | H. Fire detection control panels |
| C. Workshop entry hatch              | I. Intercom                      |
| D. Handrails                         | J. Fire extinguisher             |
| E. Air circulation ducts             | K. Water tank                    |
| F. Air mixing chamber                | L. Television input station      |

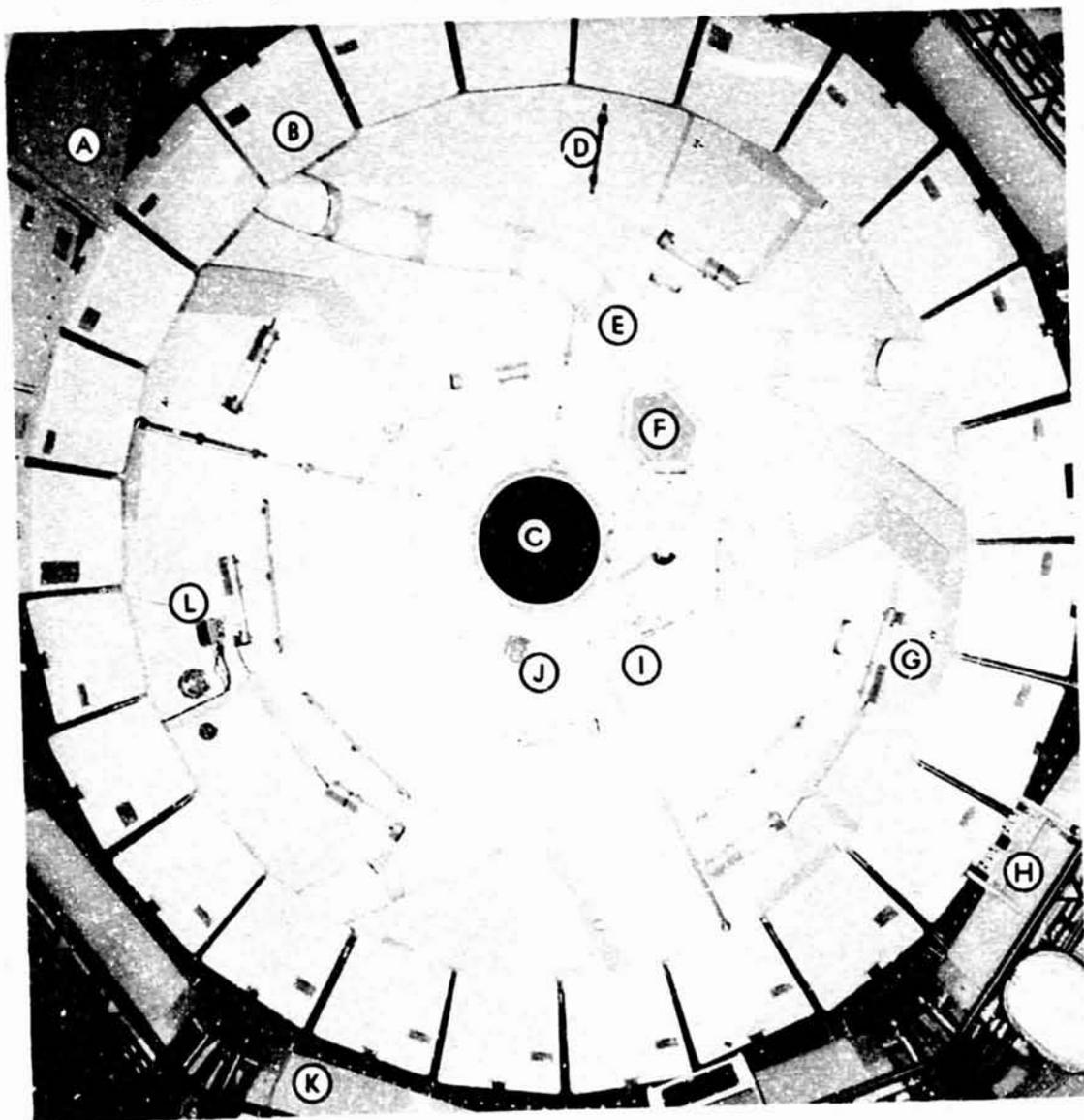


Figure 2-7.- Workshop forward compartment dome looking forward toward the airlock.

cabinets. This area has a floor and is arranged with most of the experiment equipment oriented to the floor. Figure 2-8 is a view looking aft in the workshop. Most of the floor is an open grid, so that part of the aft area can also be seen in this photograph.

- |                          |  |
|--------------------------|--|
| A. Film vault            | F. Food freezer                                  |
| B. Stowage lockers       | G. Food storage containers                       |
| C. Air circulation ducts | H. Experiment equipment                          |
| D. Scientific airlocks   | I. Waste management compartment ventilation unit |
| E. Trash airlock         |  |

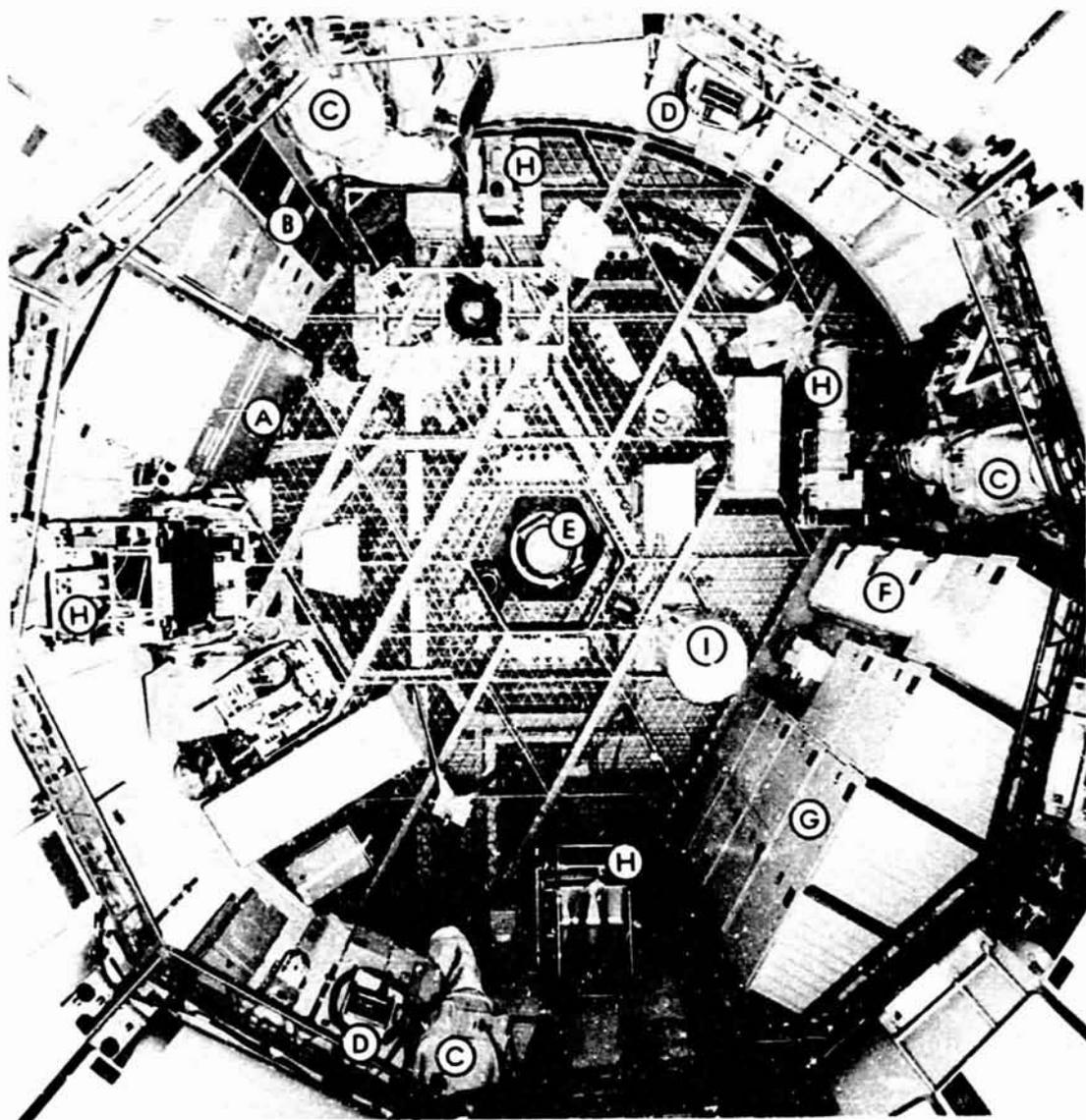


Figure 2-8.- Workshop forward area looking aft from the airlock.

The aft part of the workshop contains a smaller experiment area and the crew quarters. Part of the experiment area is shown in figure 2-9. Many of the experiments can be seen as well as some more control panels and other equipment. Figure 2-10 is a view of the same area looking in the opposite direction into the wardroom. More experiment hardware is shown in this view as well as some of the equipment in the wardroom required to support the crew. The wardroom is used by the crew for cooking, eating, relaxing, and, through the circular window seen in the background, viewing the Earth. Some of the stowage lockers are visible. Figure 2-11 is a panoramic view to the right of the wardroom showing the waste management and sleep compartments. As can be seen from figures 2-9, 2-10, and 2-11, the aft area of the workshop is oriented to a floor, walls, and ceiling. Aft of this area is a large waste tank where trash is dumped. The trash airlock for these dumps can be seen in figure 2-10.

- |                                       |  |
|---------------------------------------|--|
| A. Speaker intercom assembly          | F. Lower body negative pressure experiment |
| B. General illumination lights        | G. Ergometer                               |
| C. Digital display (time)             | H. Circulating air outlets                 |
| D. Workshop electrical control panels | I. Rotating litter chair                   |
| E. Experiment support panel           |  |

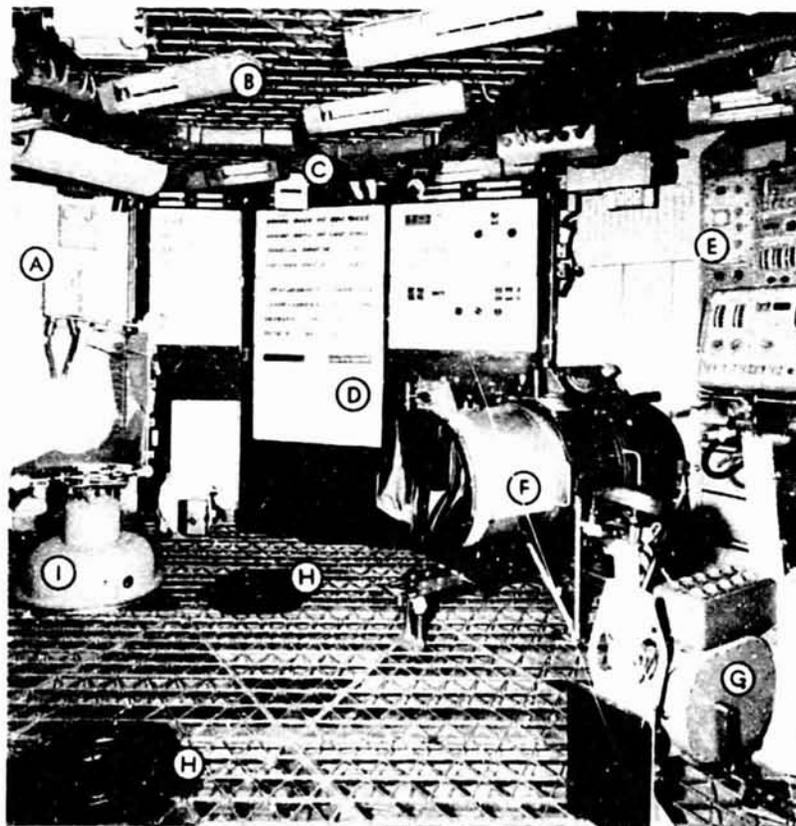
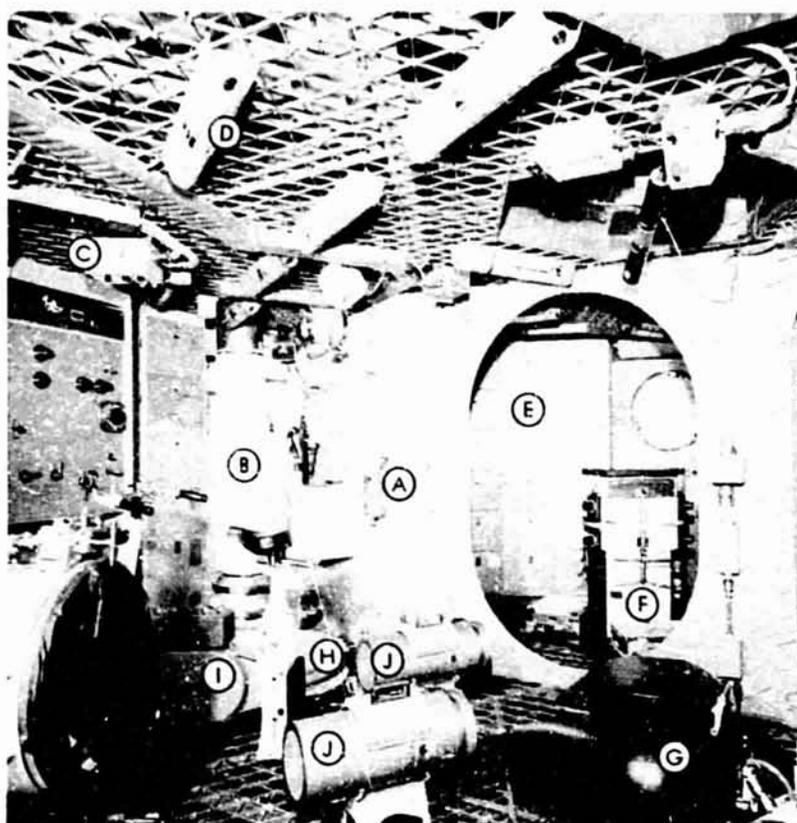


Figure 2-9.- Aft workshop experiment area.



- A. Fire extinguisher
- B. Air circulation duct
- C. Intercom
- D. General illumination lights
- E. Wardroom storage locations
- F. Food table
- G. Trash airlock
- H. Folded shower curtain
- I. Ergometer
- J. Portable fans  
(launch restraint position)

Figure 2-10.- Aft workshop experiment area and wardroom entrance.

- A. Wardroom window
- B. Access to forward area
- C. Portable hand holds
- D. Sleep area
- E. Fire sensor
- F. Waste management area
- G. Towel holders
- H. Trash airlock
- I. Food table

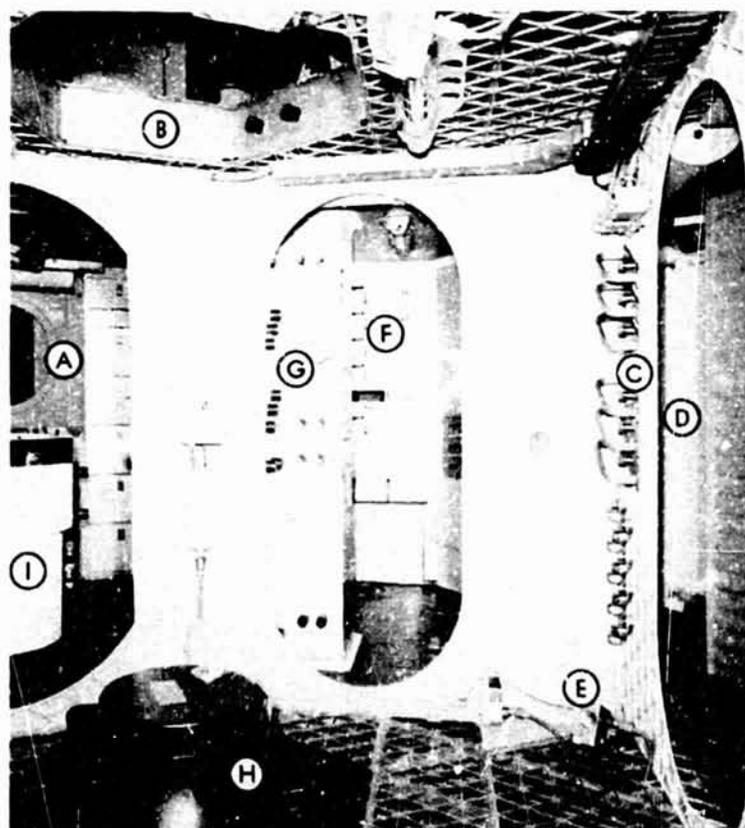


Figure 2-11.- Wardroom, waste management, and sleep areas.

A lightweight shield designed to protect the workshop from the heat of direct solar radiation and from meteoroid penetration was torn off by aerodynamic forces during launch. Damage from this resulted in the subsequent loss of workshop solar array wing 2 during separation of the Saturn Workshop from the Saturn V launch vehicle. These anomalies, described in detail in subsection 4.3, resulted in an orbital configuration slightly different from that designed.

Lack of thermal protection because of the loss of the shield required development and deployment of a protective thermal shield for the side of the workshop exposed to the Sun. Two different shields were used. The first was deployed during the first manned period through the +Z scientific airlock, which is on the side of the workshop normally facing the Sun. Because of potential deterioration of the material in this shield, another shield of different design was installed by the second crew during an extravehicular activity. This shield provided thermal protection during the remainder of the mission. A photograph of the final Saturn Workshop orbital configuration is shown in figure 2-12. In the photograph, two corners of the first shield may be seen protruding from below the edges of the second shield. The absence of one workshop solar array is evident.

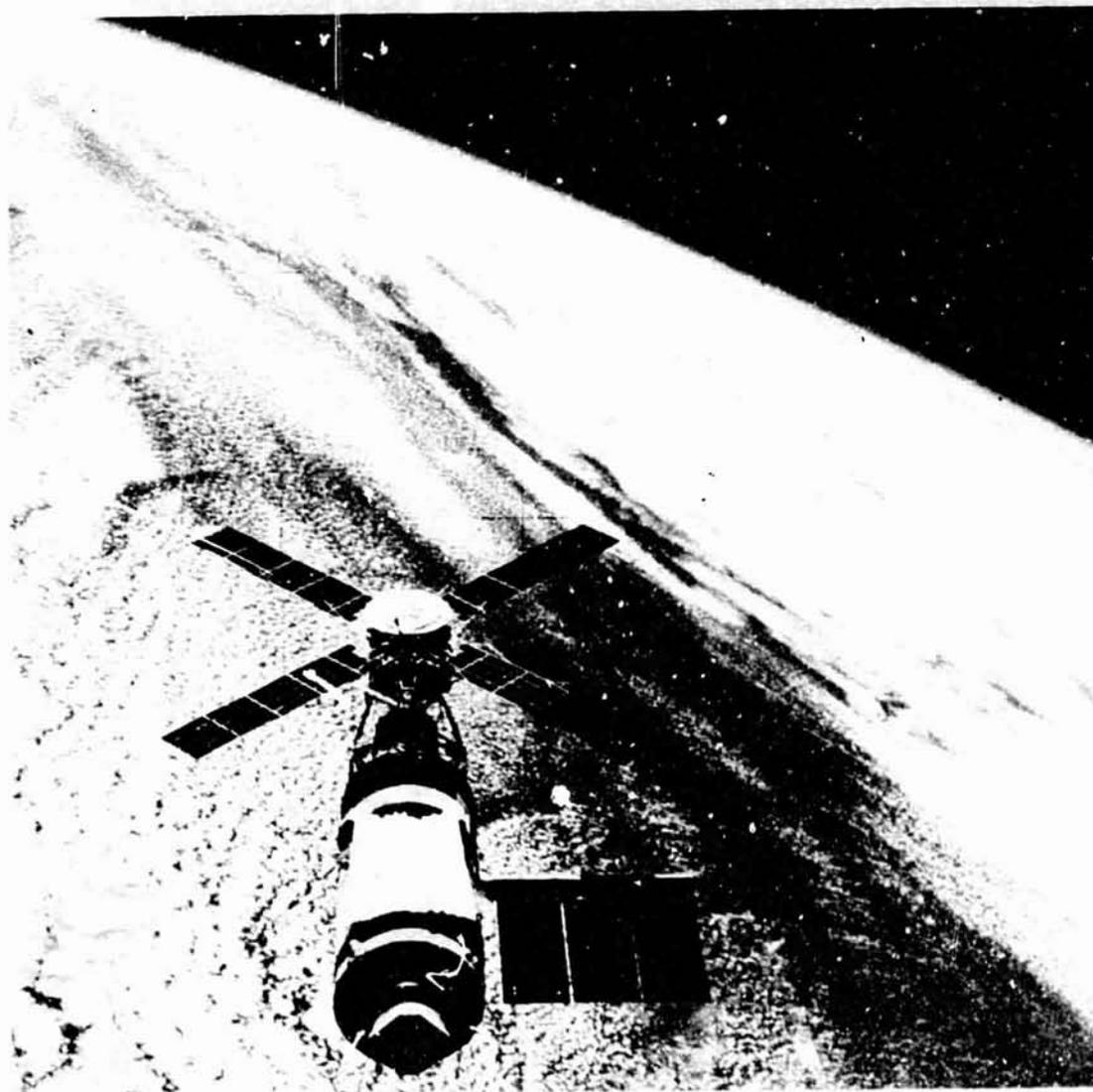


Figure 2-12.- Saturn Workshop in orbit.

### SECTION 3

## MISSION SUMMARY

The mission of the Skylab to accommodate men and conduct experiments over a long term operation was successful. Operation of Skylab's many complex systems expanded man's knowledge of space science and technology and provided insight for future applications. General aspects of manned space station requirements such as redundancy, backup operations, maintenance, long duration habitability, and communications were tested. A benefit beyond the vast amounts of immediately applicable information gathered was practical experience on the degree of design sophistication and conservatism required in this environment for long term operation. This information will help to estimate costs and improve efficiency on future programs.

The frequency and duration of the Skylab manned periods were based primarily on medical considerations, taking into account previous experience and following an incremental increase in duration for experimental purposes. The time between manned periods was used for preparing for the next launch and assessing mission results, including the condition of the crew. Rescue capability was possible by means of an expedited preparation and checkout of the next launch vehicle plus installation of the rescue kit in the command module.

A preliminary mission plan, based on the established mission objectives and known constraints, was developed to guide hardware design. From this point refinements and trade-offs were made until a final mission plan was developed. This plan called for placing the Saturn Workshop in a low Earth orbit to accommodate three 3-man crews (fig. 3-1) for periods of 28, 56, and 56 days, respectively. Unmanned periods of 1, 60, and 30 days, respectively, were to precede the three manned periods, resulting in a planned mission of 231 days.

The actual mission duration was 272 days, with manned periods of 28, 59, and 84 days. Preceding the manned periods were three unmanned periods of 11, 36, and 52 days. After the third crew left, ground control devoted the final 2 days to systems tests and preparations for orbital storage. The first unmanned period was extended to provide time for analysis, planning, fabrication, stowage, and training for repairs made necessary by the launch phase anomaly. The second unmanned period was shortened to return a crew as quickly as possible to attend to spacecraft repairs. The third unmanned period was extended so that the third manned period would coincide with prime opportunities for viewing the newly discovered Comet Kohoutek. The second and third manned periods were extended to obtain additional experimental data. Figure 3-2 shows the overall mission profile, and the overall mission day reference is presented in table 3-I.

The Saturn Workshop was active for the entire mission. Activities consisted essentially of experimentation and station operation. When a crew was onboard, experimentation was greatly increased, and, of course, the functions related to habitation were performed, including crew leisure activities and recreation.



Astronaut  
Charles Conrad, Jr.  
Commander

Scientist-Astronaut  
Joseph P. Kerwin  
Science Pilot

FIRST SKYLAB CREW

Astronaut  
Alan L. Bean  
Commander

Scientist-Astronaut  
Owen K. Garriott  
Science Pilot

Astronaut  
Jack R. Loosma  
Pilot

SECOND SKYLAB CREW

Astronaut  
Gerald P. Carr  
Commander

Scientist-Astronaut  
Edward G. Gibson  
Science Pilot

Astronaut  
William R. Pogue  
Pilot

THIRD SKYLAB CREW

Figure 3-1.- Skylab prime crews.

Several activities not originally planned were performed as a result of operational problems and the extensions of manned periods. Also, additional experiments, tests, and demonstrations were made possible by better-than-expected crew efficiency.

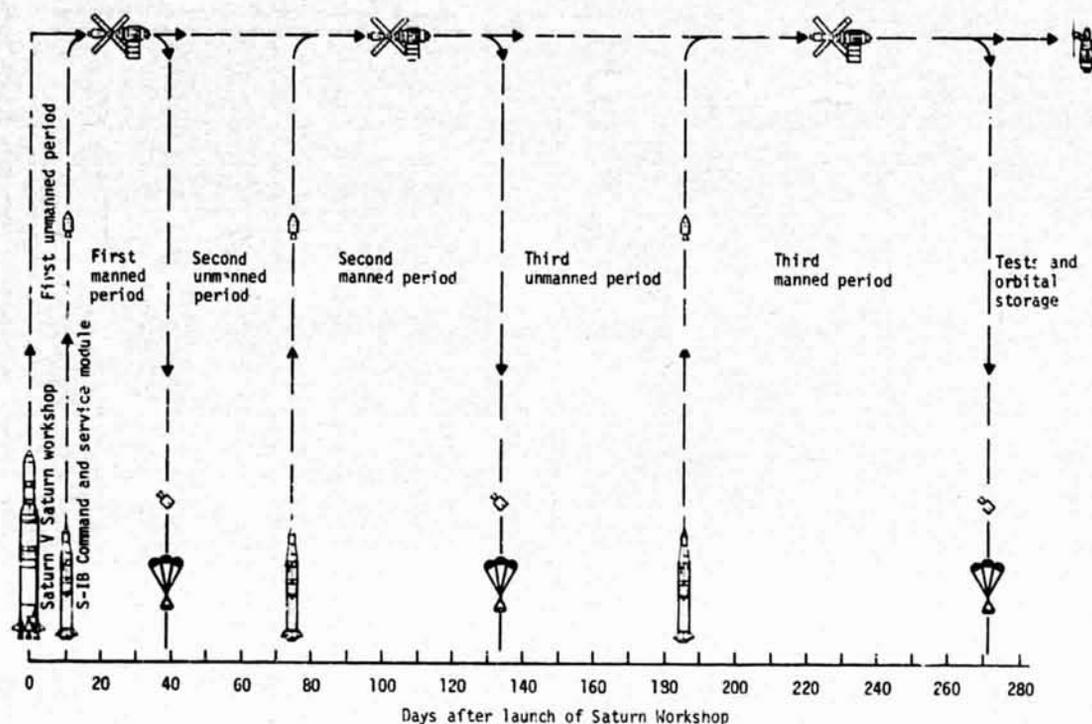


Figure 3-2.- Mission profile.

### 3.1 SATURN WORKSHOP LAUNCH

The Saturn Workshop was launched (fig. 3-3) at 17:30 Gmt on May 14, 1973 (Day 1), from Launch Complex 39A at Kennedy Space Center, Florida. The launch vehicle consisted of the first two stages of a Saturn V. At 63 seconds into flight, there were indications that the workshop's meteoroid shield had deployed and that the workshop solar array wing 2 was no longer secured in its launch position. The Saturn Workshop separated from the second stage 591 seconds after launch. Two seconds later, all measurements from wing 2 went offscale, indicating some failure. At approximately 599 seconds after launch, the Saturn Workshop entered a nearly circular orbit at approximately 435 kilometers altitude, inclined 50 degrees to the Equator. The orbital velocity was 7.649 km/sec, and the period was approximately 93 minutes. Specific details concerning the launch vehicle performance can be found in reference 13.

The orbit had been planned to give a ground track which repeated about every 5 days, for recurrent coverage of surface features of the Earth. However, the orbital insertion velocity was slightly high, causing the ground track to drift westward. A trim maneuver on Day 16 using the command and service module's reaction control system stabilized a repeating ground track slightly west of that planned for the mission. A second trim maneuver, on Day 35, established a drift of the ground track that would move it back toward that planned. The space environment parameters encountered were well within the safe ranges anticipated.

Table 3-I.- Saturn Workshop Mission Day Reference

DAY	DATE (1971)	DAY OF YEAR	MISSION PERIODS	DAY	DATE (1973)	DAY OF YEAR	MISSION PERIODS	DAY	DATE (1973)	DAY OF YEAR	MISSION PERIODS	DAY	DATE (1973-74)	DAY OF YEAR	MISSION PERIODS
1	5-14	134		70	7-22	203		138	9-28	271		206	12-5	339	
2	5-15	135		71	7-23	204		139	9-29	272		207	12-6	340	
3	5-16	136		72	7-24	205		140	9-30	273		208	12-7	341	22
4	5-17	137		73	7-25	206		141	10-1	274		209	12-8	342	23
5	5-18	138		74	7-26	207		142	10-2	275		210	12-9	343	24
6	5-19	139		75	7-27	208		143	10-3	276		211	12-10	344	25
7	5-20	140		76	7-28	209	1	144	10-4	277		212	12-11	345	26
8	5-21	141		77	7-29	210	2	145	10-5	278		213	12-12	346	27
9	5-22	142		78	7-30	211	3	146	10-6	279		214	12-13	347	28
10	5-23	143		79	7-31	212	4	147	10-7	280		215	12-14	348	29
11	5-24	144		80	8-1	213	5	148	10-8	281		216	12-15	349	30
12	5-25	145	1	81	8-2	214	6	149	10-9	282		217	12-16	350	31
13	5-26	146	2	82	8-3	215	7	150	10-10	283		218	12-17	351	32
14	5-27	147	3	83	8-4	216	8	151	10-11	284		219	12-18	352	33
15	5-28	148	4	84	8-5	217	9	152	10-12	285		220	12-19	353	34
16	5-29	149	5	85	8-6	218	10	153	10-13	286		221	12-20	354	35
17	5-30	150	6	86	8-7	219	11	154	10-14	287		222	12-21	355	36
18	5-31	151	7	87	8-8	220	12	155	10-15	288		223	12-22	356	37
19	6-1	152	8	88	8-9	221	13	156	10-16	289		224	12-23	357	38
20	6-2	153	9	89	8-10	222	14	157	10-17	290		225	12-24	358	39
21	6-3	154	10	90	8-11	223	15	158	10-18	291		226	12-25	359	40
22	6-4	155	11	91	8-12	224	16	159	10-19	292		227	12-26	360	41
23	6-5	156	12	92	8-13	225	17	160	10-20	293		228	12-27	361	42
24	6-6	157	13	93	8-14	226	18	161	10-21	294		229	12-28	362	43
25	6-7	158	14	94	8-15	227	19	162	10-22	295		230	12-29	363	44
26	6-8	159	15	95	8-16	228	20	163	10-23	296		231	12-30	364	45
27	6-9	160	16	96	8-17	229	21	164	10-24	297		232	12-31	365	46
28	6-10	161	17	97	8-18	230	22	165	10-25	298		233	1-1	1	47
29	6-11	162	18	98	8-19	231	23	166	10-26	299		234	1-2	2	48
30	6-12	163	19	99	8-20	232	24	167	10-27	300		235	1-3	3	49
31	6-13	164	20	100	8-21	233	25	168	10-28	301		236	1-4	4	50
32	6-14	165	21	101	8-22	234	26	169	10-29	302		237	1-5	5	51
33	6-15	166	22	102	8-23	235	27	170	10-30	303		238	1-6	6	52
34	6-16	167	23	103	8-24	236	28	171	10-31	304		239	1-7	7	53
35	6-17	168	24	104	8-25	237	29	172	11-1	305		240	1-8	8	54
36	6-18	169	25	105	8-26	238	30	173	11-2	306		241	1-9	9	55
37	6-19	170	26	106	8-27	239	31	174	11-3	307		242	1-10	10	56
38	6-20	171	27	107	8-28	240	32	175	11-4	308		243	1-11	11	57
39	6-21	172	28	108	8-29	241	33	176	11-5	309		244	1-12	12	58
40	6-22	173	29	109	8-30	242	34	177	11-6	310		245	1-13	13	59
41	6-23	174	30	110	8-31	243	35	178	11-7	311		246	1-14	14	60
42	6-24	175		111	9-1	244	36	179	11-8	312		247	1-15	15	61
43	6-25	176		112	9-2	245	37	180	11-9	313		248	1-16	16	62
44	6-26	177		113	9-3	246	38	181	11-10	314		249	1-17	17	63
45	6-27	178		114	9-4	247	39	182	11-11	315		250	1-18	18	64
46	6-28	179		115	9-5	248	40	183	11-12	316		251	1-19	19	65
47	6-29	180		116	9-6	249	41	184	11-13	317		252	1-20	20	66
48	6-30	181		117	9-7	250	42	185	11-14	318		253	1-21	21	67
49	7-1	182		118	9-8	251	43	186	11-15	319		254	1-22	22	68
50	7-2	183		119	9-9	252	44	187	11-16	320	1	255	1-23	23	69
51	7-3	184		120	9-10	253	45	188	11-17	321	2	256	1-24	24	70
52	7-4	185		121	9-11	254	46	189	11-18	322	3	257	1-25	25	71
53	7-5	186		122	9-12	255	47	190	11-19	323	4	258	1-26	26	72
54	7-6	187		123	9-13	256	48	191	11-20	324	5	259	1-27	27	73
55	7-7	188		124	9-14	257	49	192	11-21	325	6	260	1-28	28	74
56	7-8	189		125	9-15	258	50	193	11-22	326	7	261	1-29	29	75
57	7-9	190		126	9-16	259	51	194	11-23	327	8	262	1-30	30	76
58	7-10	191		127	9-17	260	52	195	11-24	328	9	263	1-31	31	77
59	7-11	192		128	9-18	261	53	196	11-25	329	10	264	2-1	32	78
60	7-12	193		129	9-19	262	54	197	11-26	330	11	265	2-2	33	79
61	7-13	194		130	9-20	263	55	198	11-27	331	12	266	2-3	34	80
62	7-14	195		131	9-21	264	56	199	11-28	332	13	267	2-4	35	81
63	7-15	196		132	9-22	265	57	200	11-29	333	14	268	2-5	36	82
64	7-16	197		133	9-23	266	58	201	11-30	334	15	269	2-6	37	83
65	7-17	198		134	9-24	267	59	202	12-1	335	16	270	2-7	38	84
66	7-18	199		135	9-25	268	60	203	12-2	336	17	271	2-8	39	85
67	7-19	200		136	9-26	269		204	12-3	337	18	TESTS & ORBITAL STORAGE			
68	7-20	201		137	9-27	270		205	12-4	338	19	272	2-9	40	
69	7-21	202										273	2-10	41	

Meteoroid and radiation hazards were extremely low, and the South Atlantic Anomaly provided, as expected, the highest radiation level .

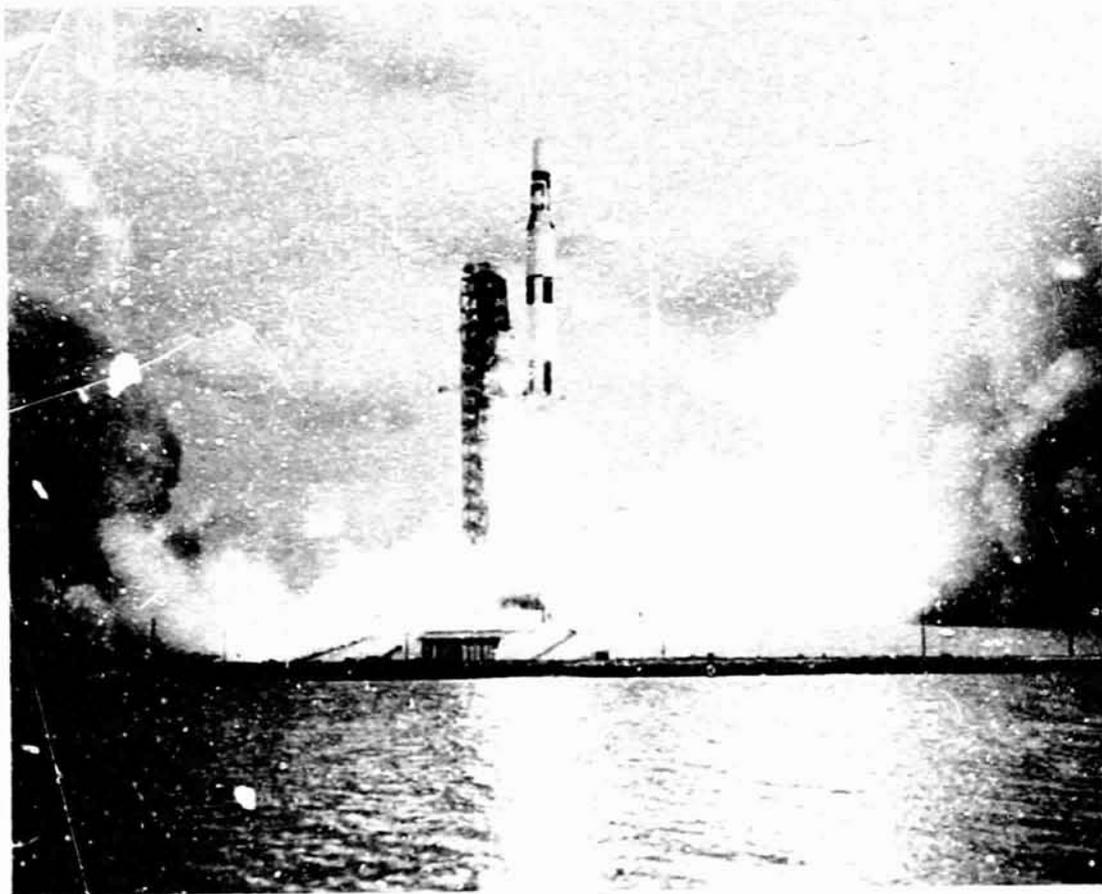


Figure 3-3.- Saturn Workshop launch.

Communication between the Saturn Workshop and the ground was limited to the time the vehicle was within range of 1 of the 13 ground communication sites located around the Earth. Ground contact was possible approximately 32 percent of the flight time, and individual site contacts varied between 2 and 11 minutes. In some cases the site antenna patterns overlapped, giving as much as 18 to 20 minutes of continuous signal, and in other cases as much as 90 minutes elapsed between site contacts. The site locations and typical ground tracks are shown in figure 3-4. The communication ground sites were already established from previous programs, and though Skylab's orbital inclination was considerably higher than that for previous manned flights, they were sufficient with some adjustments. The upper inclination limit was constrained by launch vehicle performance, safety considerations such as where launch vehicle debris would fall, and where the crew could safely land.

### 3.2 FIRST UNMANNED PERIOD

After the Saturn Workshop was inserted into orbit a sequence of deployment and activation procedures began. The first event in the sequence was the jettisoning of the shield which protected the refrigeration system radiator from

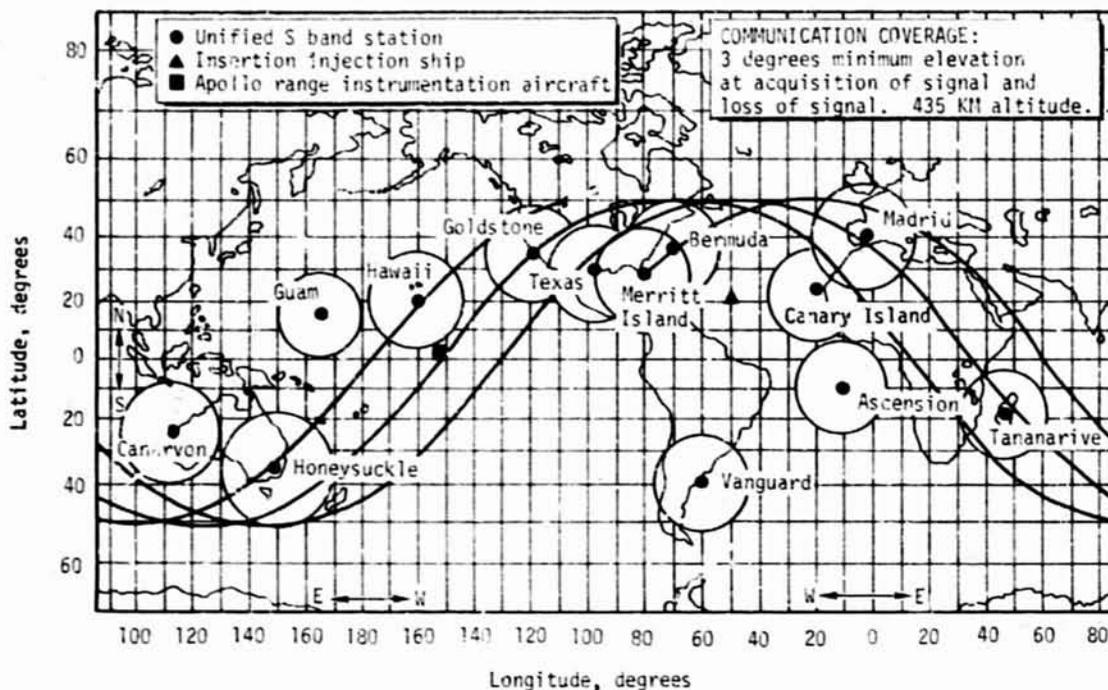


Figure 3-4.- Ground communications site locations and typical orbital ground tracks.

contamination during the separation sequence. The Saturn Workshop then was maneuvered into a gravity gradient attitude with the docking adapter pointed toward the center of the Earth. The refrigeration system, for maintaining the frozen food, was activated, and the shroud covering the solar observatory and docking adapter was jettisoned. The Saturn Workshop was then maneuvered to the solar inertial attitude and the solar observatory and its solar array were deployed. The final steps in this sequence would have been deployment of the workshop's solar array wings and the meteoroid shield surrounding the workshop, but near the end of the first orbit the normal deployment indications had not been received.

Over the Goldstone ground station, another workshop solar array beam deployment command was transmitted. There were indications that the command was received, but no indication of any action. In case there had been an instrumentation failure, the backup command to deploy the meteoroid shield was then transmitted through the Honeysuckle station. There were indications that the command was received, but again there were no indications of any positive results. At that point, it was obvious that there were problems with the meteoroid shield and the solar array wings. Preliminary analyses indicated that some or all of the meteoroid shield had been lost, and one array was probably gone. The loss of the shield left the surface of the workshop exposed to solar radiation which caused its temperature to be about 200°F higher than it had been designed for. It was not known whether the whole shield had been lost. The status of the solar array beams also was unknown. There were indications that one of the workshop's solar arrays was gone completely and that the other array was only partially deployed.

The launch of the first crew, which was supposed to have followed the launch of the Saturn Workshop by 1 day, was delayed for 10 days to allow time for assessing the situation and deciding the steps to be taken. Assignments were sent out to various National Aeronautics and Space Administration centers and contractors. Marshall Space Flight Center was asked to conduct a series of analytical studies to predict the effects of what was known from telemetry. These activities included predictions of what the temperatures would be in the film vaults, the food lockers, and the medicine containers and what effect high temperatures would have on the polyurethane foam insulation bonded to the inner wall of the workshop. If the temperatures in the unrefrigerated food lockers and film vaults exceeded the specification limits the food would spoil and the very sensitive film would fog. It was necessary to put the Saturn Workshop into an attitude that would keep the temperatures as low as possible.

Through analysis and experimentation the optimum attitude for the Saturn Workshop was sought. To reduce the incidence of the Sun's rays on the workshop and thereby reduce overheating to the maximum extent possible, the Saturn Workshop was placed in a position where the solar observatory solar arrays were no longer fully effective. Then the batteries were endangered, and the changing attitude also caused the auxiliary cooling systems to approach the freezing temperature. It was approximately 14 hours into the flight before an attitude was found that would be suitable both thermally and electrically. Workshop internal temperatures reached approximately 130°F, and the essential systems were maintained with the electrical power available.

Meanwhile, it was concluded that the Saturn Workshop had, in fact, lost almost all of the meteoroid shield and the whole workshop array wing 2, and that array wing 1 was restricted from deploying. Simultaneously several organizations independently conceived ways in which a thermal shield could be rigged by the crew to make the Saturn Workshop habitable.

Johnson Space Center designed a parasol thermal shield to fit in a small canister that had been designed to house an experiment to be deployed through the scientific airlock which is on the side of the workshop normally facing the Sun. It operated much as a normal parasol, having four struts and a center post. The center post was held by the crew in the workshop, and the struts were shoved out through the canister extending through the +Z scientific airlock. The struts were spring loaded so that they extended when they cleared the canister.

Another Johnson Space Center concept was to let the crew rig a shield while standing in the open command module hatch. The crew was to take a fabric shield and, using poles with hooks at their ends, attach pulleys and ropes to the Saturn Workshop to rig up a shade. This concept seemed simple, but the necessity for keeping the command module close to the Saturn Workshop and the uncertainty of the crew's being able to tie the shield firmly using a pole led to retaining this concept only as an alternate method.

Marshall Space Flight Center developed a thermal shield concept which required the crew to perform an extravehicular activity, going out the airlock and hanging a fabric thermal shield from a twin-pole frame. The top of the frame would be attached at the solar observatory work station, then the 55-foot-long poles would be extended down the side of the workshop, and the thermal shield would be stretched between the poles.

The Langley Research Center developed a concept utilizing Echo Satellite type material. This was an umbrella made of aluminized material held in place by inflated balloon ribs running its length and width. These ribs would be tied to the workshop's structure. Among other concepts suggested but not used for various reasons were painting of the workshop exterior, a bungee-connected shield, and a weather balloon.

In an effort concurrent with the development of the thermal shield, Marshall Space Flight Center was asked to determine what could be done about freeing the remaining workshop solar array wing. There was no way to determine what was preventing the deployment of the solar array wing, so all alternatives had to be investigated. However, one problem almost certainly involved the solar array beam's actuator-damper, which resembles an automobile's hydraulic shock absorber. This cylinder moves the beam out when it is released in the normal mode. Originally the beam was to be deployed immediately upon reaching orbit, but since that could not be done, the actuator had had a chance to cool to about  $-50^{\circ}\text{F}$ , which was near the hydraulic fluid's freezing point. There was a high probability that the actuator-damper attachment would have to be broken to deploy the beam.

A related problem was that the solar array wing sections, which unfold in accordion-like fashion from the beam, also have actuator-dampers like the one for deploying the beam. The only differences were that the actuators contained a less viscous fluid and were mounted in such a position that they could be exposed to the Sun after beam deployment. It was hoped the Sun could warm them so that the wing sections would deploy.

In addition to the loss of the meteoroid shield, the loss of one workshop solar array wing, and the failure of the other to deploy, another problem was apparent. The workshop has polyurethane foam bonded to the internal walls for insulation. At temperature and pressure conditions similar to those that existed in the workshop, the decomposition of polyurethane creates gases which can be dangerous. Extensive and accelerated tests were made to determine the decomposition that might occur at the high workshop temperatures.

With personnel working around the clock, meetings were held to determine what simulators and mockups were needed, which thermal models were to be used, when procedures and training facilities were required, which manufacturing personnel were needed, what computer facilities were required, and how crew participation should be scheduled, all in support of the four major problems being worked. Testing of various materials for use in the thermal shield proceeded, since whatever the thermal shield structure concept chosen, a shield material would be needed. When the structural designs were completed, static and dynamic testing was performed. Figure 3-5 shows the fabrication of the parasol. Initial tests were performed in the neutral buoyancy tank at Marshall Space Flight Center to confirm the design and to assist in developing deployment procedures. This facility simulates in a large water tank the zero-gravity condition of space and is used to develop crew procedures that will work in zero gravity. Full-scale mockups were placed in the tank and used for the thermal shield deployment tests.

Testing of the polyurethane insulation provided confidence that the insulation would not separate from the workshop's walls and that there would be no loose particles. However, it was found that appreciable amounts of gases were emitted from the insulation at  $300^{\circ}\text{F}$ . Updated information was obtained from

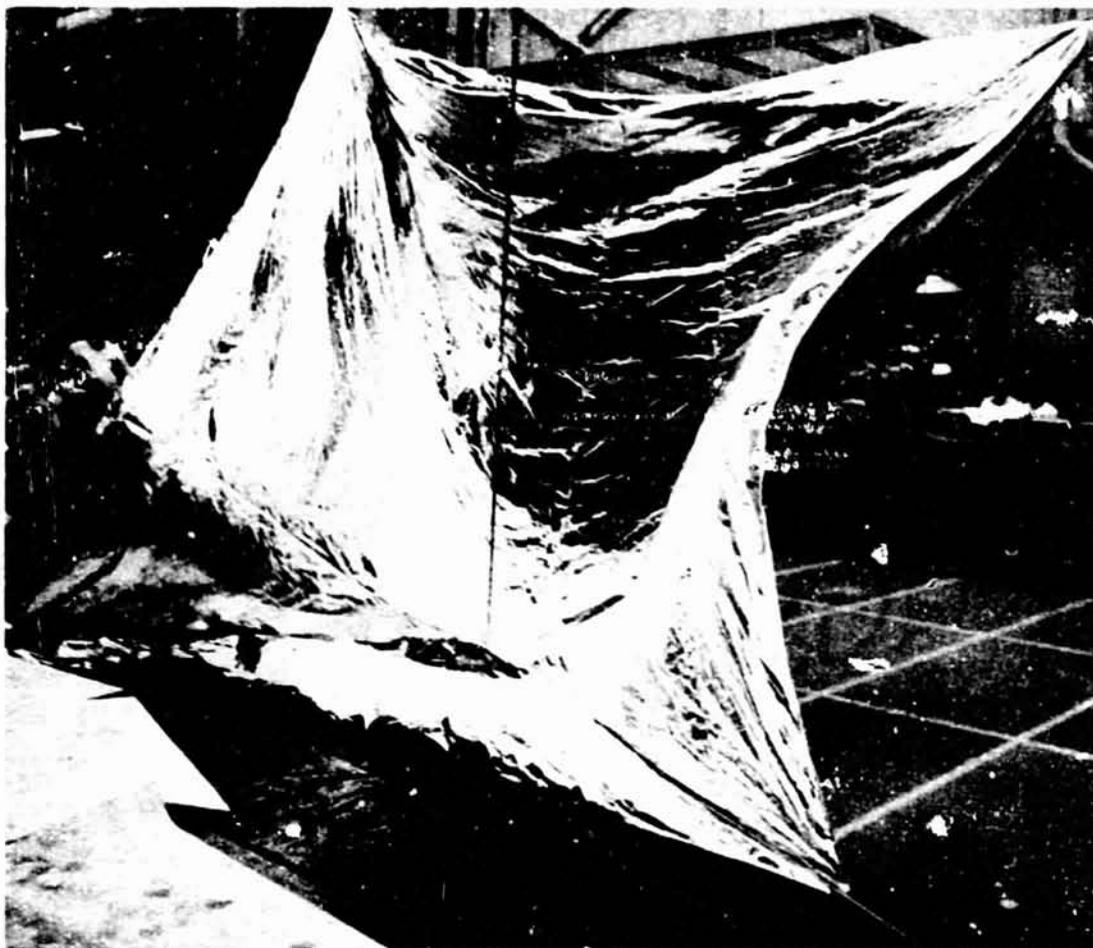


Figure 3-5.- One step in the fabrication of the parasol thermal shield.

flight data on heat exposures of the vehicle and retesting was initiated. Tests indicated that even though gas might be coming out of the walls, the internal volume was sufficient to dilute this to extremely low levels. As a further precaution, starting on Day 8 the laboratory was depressurized and repressurized to flush overboard any toxic gases contained in the laboratory. This pressure cycling continued for 3.5 days. Finally, the crew would wear gas masks upon entering the laboratory and would run gas analysis tests to provide full confidence in the safety of the Saturn Workshop's atmosphere.

Design, testing, and development of tools for freeing and deploying the solar array beam were begun. It was speculated that restraining debris existed in the form of bolts, sheet metal, and metal straps. A decision was made to concentrate on shear-type sheet-metal cutters and cable cutters. The tools had to be modified to provide longer handles. Once the tools were ready, a mockup command module and fragments of metal resembling the meteoroid shield, the solar array beam, wire bundles, straps, and bolted items were assembled in the neutral buoyancy tank. The first crew's Pilot, standing in the open command module hatch, performed an extravehicular activity in the tank. The crew trained in cutting straps and sheet metal in the weightless environment. Three tools, the

cable cutters, the shears, and a universal handling tool, were evaluated, approved, and shipped to Kennedy Space Center for stowage in the command and service module. Calculations showed that once the beam was deployed, the wing sections would unfold as the Sun warmed the deploying cylinders.

As the concepts for the thermal shield were developed it became obvious that stowage constraints in the command module would allow only the three most feasible versions to be stowed. These were the parasol, the shield deployed from the command module, and the twin-pole shield. Development continued and on Day 9 the crew for the first manned period entered the tank for training in deployment of the shields. Figure 3-6 shows a backup crewman in the tank verifying the deployment procedures of the twin-pole shield concept.

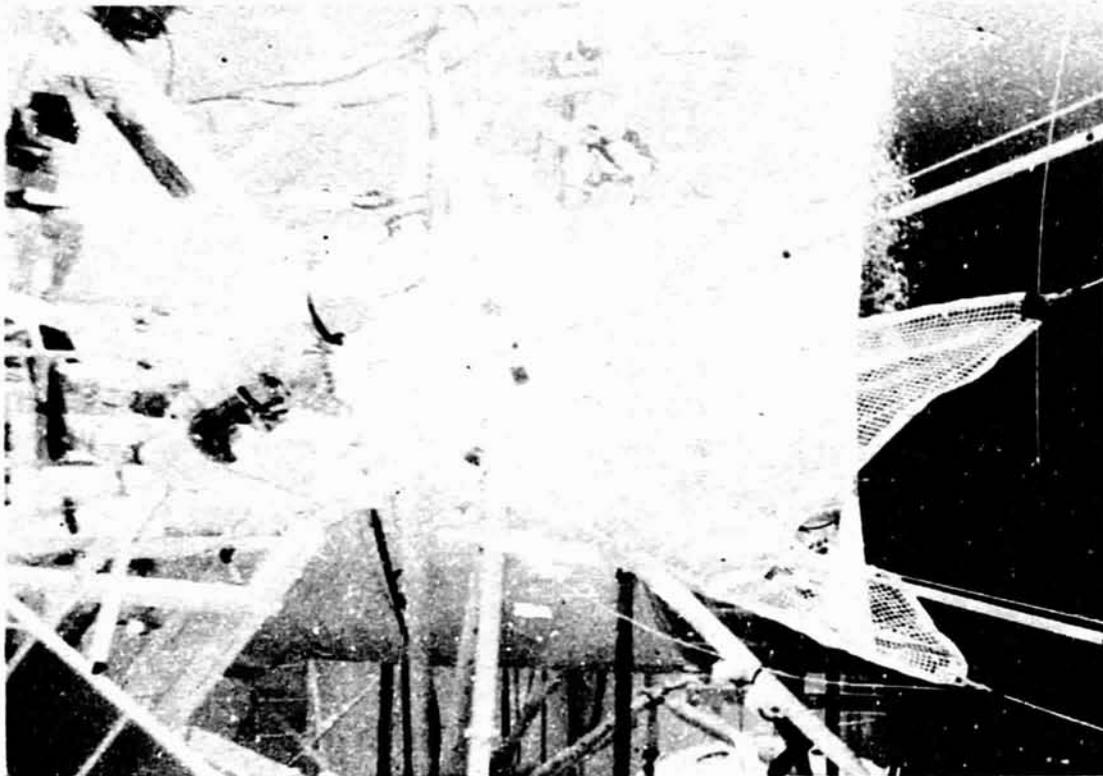


Figure 3-6.- Twin-pole thermal-shield deployment in neutral buoyancy tank.

On Day 10 a formal examination was held of all the materials testing, failures, analyses, deployment procedures, and everything associated with the design of the three thermal shields. On the basis of this review it was decided to use the parasol as the primary device and to deploy the twin-pole shield over the parasol at some later time. The parasol was favored because it could be deployed from inside Skylab. Concern had been expressed about potential problems in performing an extravehicular activity too early in the mission. The shield to be rigged from the command module was also to be stowed in the command module as a backup device.

Besides the thermal shields and tools for releasing the solar array wing, other new items were stowed in the command module, including additional cameras for the flyaround assessment, equipment for performing the extravehicular activity

from the open command module hatch, and toxic-fume-protection-detection equipment. Some items such as drugs, medications, and experiment film were stowed as replacements because of the possibility of damage from the high temperatures in the workshop.

Meanwhile, a program of careful management of attitude and power had been instituted to keep temperatures within the workshop as low as possible while providing enough power to keep the Saturn Workshop operational. Available power was strictly allocated, and, as far as possible, systems using power were turned off or operated intermittently. Heaters, one coolant pump, and telemetry transmitters, for example, were cycled on and off or were operated in reduced power modes. The electrical power systems themselves were also managed to check out and protect the systems. The two major problems, high workshop temperatures and a general power shortage, still existed at liftoff of the launch vehicle carrying the first crew.

A sequence of the major events that occurred during the first unmanned period is shown in figure 3-7.

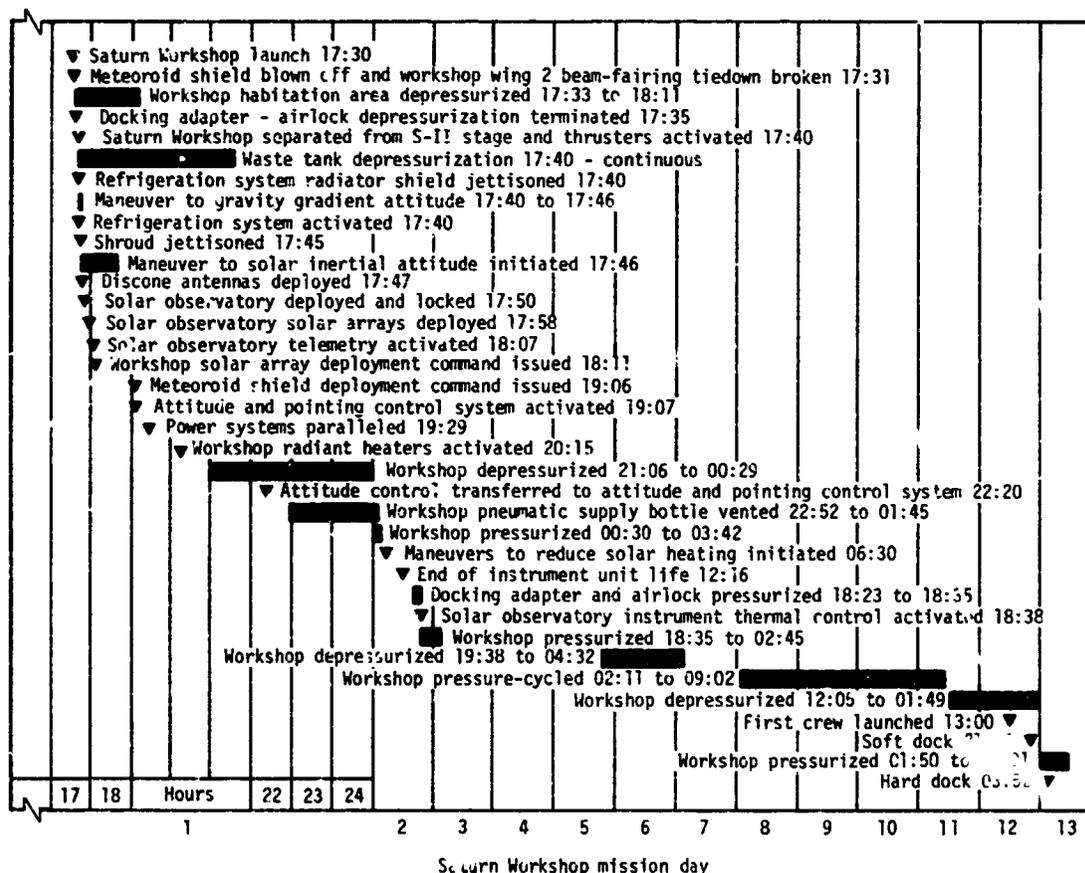


Figure 3-7.- Summary of events of first unmanned period.

### 3.3 FIRST MANNED PERIOD

The command and service module carrying the first crew was launched at 13:00 Gmt on Day 12 from Launch Complex 39B at Kennedy Space Center, Florida,



Figure 3-8.- Launch of the first crew on a Saturn IB.

on a Saturn IB launch vehicle (fig. 3-8). The crew consisted of Captain Charles Conrad, Jr., USN, Commander; Commander Joseph P. Kerwin, USN, Science Pilot; and Commander Paul J. Weitz, USN, Pilot. The primary planned objectives assigned for the first manned period were to operate the Saturn Workshop for up to 28 days, to obtain data for evaluating the performance of the crew and of the Saturn Workshop, to obtain medical data on the crew, and to perform inflight experiments. However, additional objectives now faced the crew as the Saturn Workshop had to be made operational and livable.

### 3.3.1 Activation

The command and service module, on rendezvousing with the Saturn Workshop, made a flyaround inspection. During this inspection the crew described the condition of the Saturn Workshop and photographed it. They transmitted 15 minutes of live television to the ground as they crossed the United States. The crew confirmed that the meteoroid shield was missing, that workshop solar array wing 2 was missing, and that wing 1 was partially deployed and restrained by a piece of the meteoroid shield. Figure 3-9 shows solar array wing 1 partially deployed and solar array wing 2 missing.

When the flyaround inspection was completed, the command and service module was soft-docked to the Saturn Workshop's docking adapter. The initial connection between the two docking vehicles is by means of a probe on the command module which engages a small ring in the drogue assembly in the docking adapter. Capture

latches on the probe project outward and engage the ring, soft-docking the vehicle. The second step in the docking procedure is the retraction of the probe into the command module, drawing the two spacecraft together. Twelve latches around the circumference of the main docking ring then engage the docking tunnel and hold the two craft together in a hard dock.

Soft docking relieved the crew from having to "station-keep"--fly the command and service module in formation with the Saturn Workshop--while they ate and prepared for the attempt to free the solar array. When the preparations were completed, the command and service module was undocked and the Pilot, using a 10-foot pole with a hook on the end, attempted to free the solar array beam. The Pilot leaned out the command module hatch, the Science Pilot held his legs to stabilize

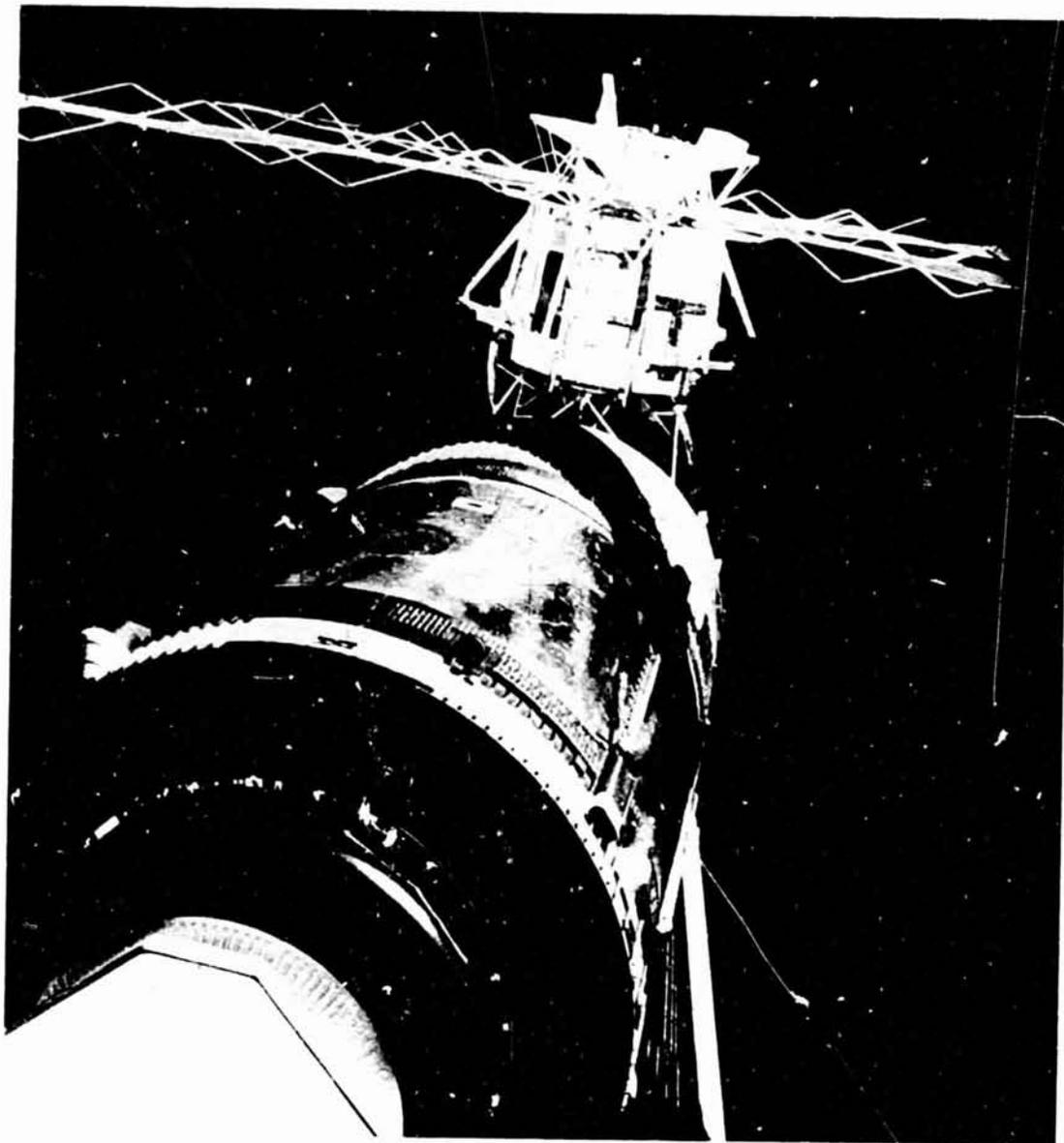


Figure 3-9.- Workshop solar array wing 1 in partially deployed position and solar array wing 2 missing.

him, and the Commander maneuvered the command and service module. The Pilot could not pry loose the strap, which was part of the meteoroid shield debris, from the beam fairing around which it was wrapped (fig. 3-10). Repeated tugging pulled the command and service module and the Saturn Workshop together. The Commander continually had to keep backing the command and service module away to avoid collision. The Saturn Workshop used a large amount of thruster gas to maintain stability in the unsuccessful attempts to free the beam.

The crew then tried to redock, but the probe capture latches failed to engage. Several attempts were made, but none was successful. The crew had to put on space suits, depressurize the command module, remove the command module forward

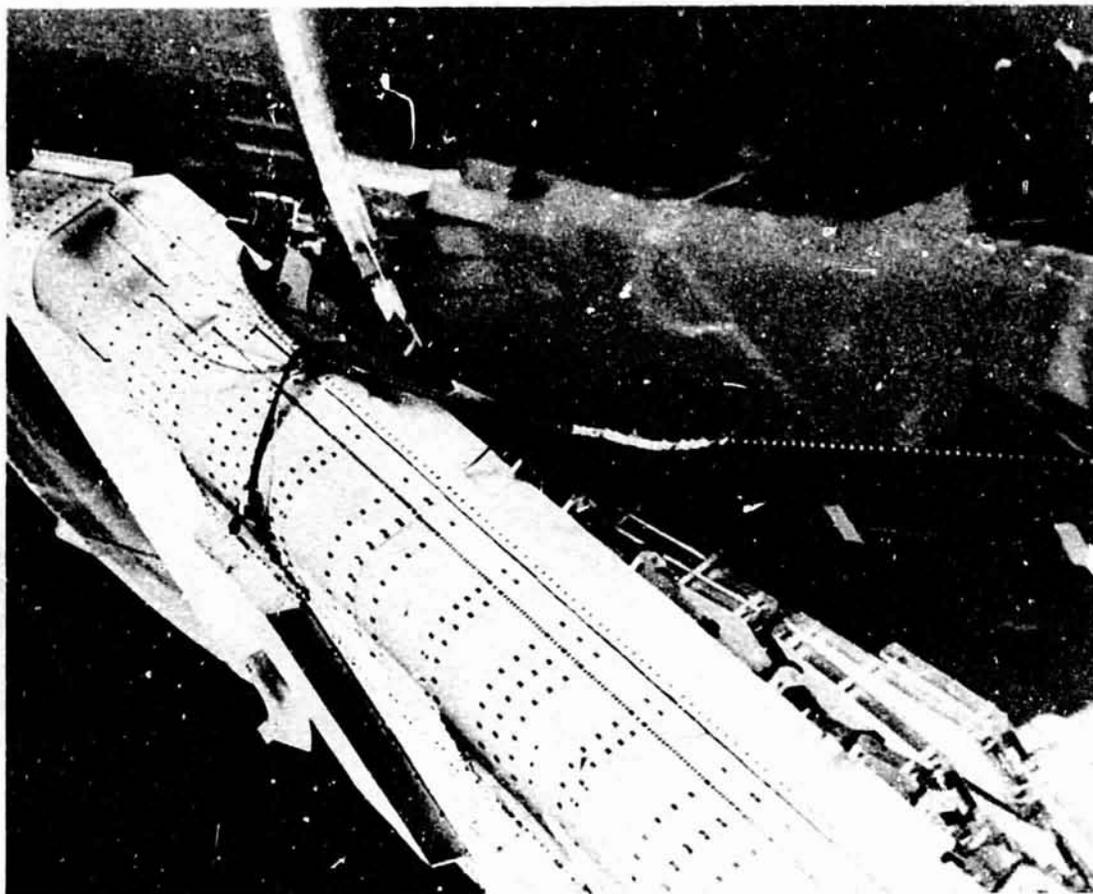


Figure 3-10.- Restraining strap on solar array wing 1 and meteoroid shield reflection.

hatch, and disassemble part of the docking probe. The command module was finally hard-docked without using the probe capture latches.

Each docking attempt disturbed the Saturn Workshop's attitude, causing the attitude control thrusters to use propellant to restore the attitude of the Saturn Workshop. A considerable amount of gas was used before docking was successfully completed. The total expenditure of gas up to this time, including that used in the frequent changes in attitude before the first crew arrived, exceeded the anticipated amount, but enough propellant remained to meet normal requirements.

After docking, the crew slept in the command module. On awakening, they ate breakfast, initiated activation of the docking adapter, donned gas masks, and entered the docking adapter tunnel. The first task was to check the atmosphere through the hatch at the pressure equalization valves for toxic substances which might have resulted from exposure of insulation to high temperatures. The atmosphere was free of toxic gases, so the Pilot and Science Pilot entered the docking adapter and completed its activation. The Pilot continued sampling the atmosphere and entered the workshop, staying in there for 1 hour and 15 minutes. The workshop was closed off while the crew ate lunch in the command module, and after lunch the crew reentered the workshop. It was 130°F in the workshop, but the humidity was so low that the crewmen could work there for 4 to 5 hours at a time.

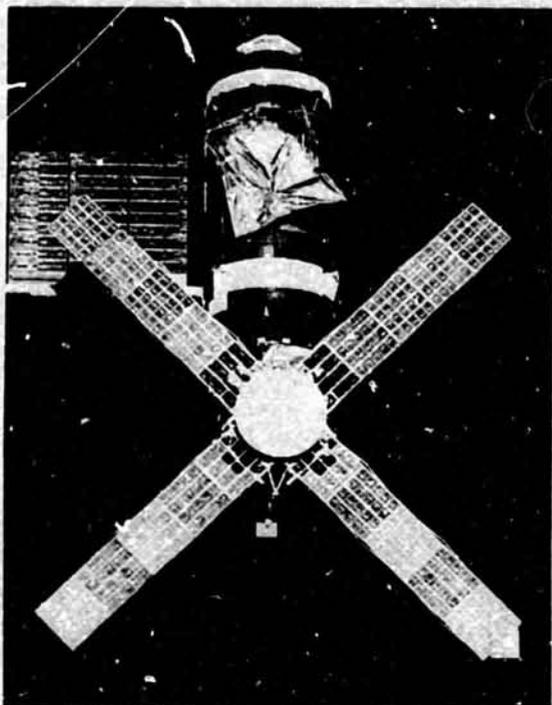


Figure 3-11.- Deployed parasol thermal shield.

Some normal activation procedures were postponed while the crew deployed the parasol thermal shield through the +Z scientific airlock. The parasol did not extend fully on one corner, because of a failure of a locking device (10.4 and fig. 3-11). After deploying the parasol, the crew continued activation of the workshop. With the parasol deployed, the temperature of the outer wall began decreasing rapidly. About 1 hour after the parasol was deployed, Skylab was placed in the solar inertial attitude. On Days 14 and 15 the crew slept in the docking adapter because of the high workshop temperature. Temperatures within the workshop were nearly normal within 4 days and were stabilized around 80°F by Day 19. After completing activation on Day 15, the crew started the planned work schedule. Operations were limited by the availability of power until solar wing 1 was deployed during an extravehicular activity on Day 25.

### 3.3.2 Operations

After completing the activation, the crew established a nearly normal routine of eating, sleeping, housekeeping, exercising, and performing experiments. Performance of the tasks necessary for the experimental program and the day-to-day maintenance was carefully scheduled, along with time for the crew to eat, sleep, and carry out other personal activities. A typical day for the crew consisted of 16 hours of activities and 8 hours of sleep. All crewmen slept at the same time on a schedule corresponding with the time at the Control Center.

In general, experiment operations were nearly as planned. Six experiments could not be performed as planned, since the workshop +Z scientific airlock was occupied by the parasol. Three of these were performed, using modified operational procedures, through the -Z, or Earth-facing, scientific airlock. Two more experiments were mounted on the solar observatory truss, and the sixth was mounted to the solar observatory sunshield. Extravehicular activities were performed to mount the latter three.

In scheduling activities, time for observations of the Earth and the Sun had to be allocated taking into consideration the orbital position of Skylab. The schedules for other activities then had to be made compatible with the requirements for these observations. All the activities for each day were incorporated in a daily flight plan, a typical example of which is shown in figure 3-12. The activities of the crew for a typical day are given in detail in table 3-II.

On Day 17 the first Earth observation experiment pass was made. There were a number of problems with three of the experiments, all of which were worked out during passes 2 through 5 on Days 20 to 23. One unplanned observation was made on Day 25 to obtain data on Hurricane Ava.



Table 3-II.- Crew Activities on Day 23

Commander	Science Pilot	Pilot
12:15 Awaken 12:15 - 12:20 Dress and reconfigure intercom		
12:30 - 12:40 Experiment T003 measurement 12:40 - 13:00 Personal hygiene 13:00 - 13:05 Record voice 13:05 - 13:25 Experiment M110 13:25 - 13:35 Experiment M071 13:35 - 13:50 Prepare breakfast 13:50 - 13:55 Eat breakfast 13:55 - 14:04 Set up for solar experiment 14:04 - 14:42 Perform solar experiment	12:20 - 12:40 Personal hygiene 12:40 - 17:50 Experiment M071 12:50 - 13:50 Experiment M110 13:50 - 14:20 Eat breakfast 14:20 - 14:55 Systems housekeeping	12:30 - 13:00 Load film cassettes 13:00 - 13:20 Personal hygiene 13:20 - 13:30 Experiment M071
14:55 - 17:55 Review plans for extravehicular activity		
17:55 - 18:05 Systems housekeeping 18:05 - 19:05 Lunch and experiment T003 19:05 - 19:25 Install experiment S019 film 19:25 - 19:40 Personal hygiene 19:40 - 19:50 Systems housekeeping 20:00 - 20:09 Set up for solar experiment 20:09 - 20:40 Perform solar experiment 20:40 - 20:45 Systems housekeeping 20:45 - 21:45 Experiment S019	17:55 - 18:40 Eat lunch 18:40 - 19:10 Systems housekeeping 19:10 - 21:30 Experiments M092, M171 21:30 - 21:45 Personal hygiene	18:40 - 19:00 Earth observations 19:00 - 19:10 Personal hygiene 19:10 - 21:30 Observe experiments M092, M171 21:30 - 21:45 Systems housekeeping 21:45 - 22:10 Stow experiment S019 film
21:45 - 23:15 Preview extravehicular activity		22:10 - 23:15 Preview extravehicular activity
23:15 - 00:05 Eat evening meal 00:05 - 02:35 Conference with ground 02:35 - 02:45 Initiate experiment S009	23:15 - 00:15 Eat evening meal 00:15 - 02:20 Presleep activities 02:20 - 02:45 Conference with ground	00:15 - 00:30 Presleep activities 00:30 - 00:49 Prepare for solar experiment 00:49 - 01:35 Perform solar experiment 01:30 - 02:20 Prepare for solar experiment
02:45 - 03:00 Presleep activities 03:00 - 11:00 Sleep		

Two hardware problems occurred early in the operations phase of the first unmanned period. The first, on Day 10, was the failure of solar observatory power conditioner 15. The power conditioners control the energy received from the solar cell panels; each consists of a battery charger, a rechargeable battery, and a load regulator. The second problem was a failure of one of the rate-sensing gyros used to maintain spacecraft attitude control. Solutions for both problems were worked out on the ground and eventually implemented during extravehicular activities.

A number of rate gyro anomalies occurred during the first 23 days after launch of the Saturn Workshop, including fundamental problems of drift, oscillations, high temperature indications, and other failures. A development program was initiated to place six modified gyros in the docking adapter. The development program was keyed to the launch of the second crew, and less than 2 months was available to perfect and deliver the new gyro package.

Meanwhile, work was still in progress on the procedures to be used in freeing the solar array wing. The Skylab ground teams used the flyaround television pictures of the restrained beam fairing as a basis for these procedures. Simulation played an important part in the procedure development because the task would have to be conducted in a weightless environment. Procedures were carefully thought out and developed with crewmen in the Marshall Space Flight Center neutral buoyancy tank. The beam fairing's actuator-damper mounting clevis would probably have to be broken before the array would deploy since the fluid was

probably frozen. The technique for breaking it was developed. The procedures were uplinked to the crew on the teleprinter (5.2.1), and on Day 25 the crew performed an extravehicular activity to free the array. The Commander positioned himself, being careful not to snag his space suit on the jagged remains of the meteoroid shield. The Science Pilot was stationed near the airlock hatch ready to assist if required. The Commander hooked a beam erection tether to the forward beam fairing vent module and secured the other end to the fixed airlock shroud. With considerable difficulty, he cut away the aluminum strap that kept the beam fairing from deploying. With the restraint removed the beam fairing deployed about 20 degrees. The Commander and the Science Pilot lugged and pulled on the beam erection tether rope and finally succeeded in breaking the actuator-damper clevis. The beam fairing immediately deployed and locked, and the wing sections partially deployed. Skylab was maneuvered to allow solar heating of the fluid in the wing section actuator-dampers. Six hours later the workshop solar array wing sections were fully deployed. The power capability increased from 4000 watts to approximately 7000 watts upon full deployment of the solar array wing.

On the ground, tests were being run on power conditioners to try to identify the failure mode of power conditioner 15. Neither the regulator nor the charger would draw power. The conclusion reached was that the input relay contactor was stuck. A procedure was developed to rap the power conditioner with a hammer to try to free the relay. This would be attempted during the extravehicular activity on Day 37.

The accomplishment of objectives during the first manned period was remarkable, especially considering the reduction in experiment time available because of the manual deployments and other system problems to be worked. All primary objectives were accomplished and most of the assigned detailed experimental objectives were completed. Of the 44 planned telecasts, 28 were performed. Since 2 of the planned telecasts were repeated, and there were 3 impromptu telecasts, the total number was 33. There were three extravehicular activities performed during the first manned period for a total of 6 hours and 20 minutes. One was performed from the open command module hatch and two were from the airlock.

Table 3-III shows the distribution of manhours for the first manned period. There were 392 hours spent on experimentation, or 20.6 percent of the time available. This percentage was reduced considerably from that planned because of the

Table 3-III.- Manhour Utilization During the First Manned Period

Activity	Manhours	Percent
Medical experiments	145.3	7.5
Solar observatory experiments	117.2	6.0
Earth observation experiments	71.4	3.7
Corollary and student experiments, and detailed test objectives	65.4	3.4
Sleep, rest, off duty	675.6	34.7
Pre- and post-sleep activity (2 meals included)	403.4	20.7
Lunch	73.7	3.8
Housekeeping	103.6	5.3
Physical training and personal hygiene	56.2	2.9
Other operations (extravehicular activity, activation and deactivation, television)	232.5	12.0
Total	1944.4	100.0

reduced power and high temperature constraints and additional tasks during the first part of the mission.

### 3.3.3 Deactivation

Day 37 was the last day of significant experimental activity. An extravehicular activity was performed to retrieve the exposed solar observatory film, and at this time the Commander rapped power conditioner 15 and succeeded in freeing the relay. The battery began charging immediately.

The remaining time was used for housekeeping and preparing for termination of the first manned period. Deactivation began during Day 38 and continued into Day 40. The major activities during this period were transferring items to be returned in the command module and setting up systems in the Saturn Workshop for ground control. The command module was reactivated on Day 40, and, after donning their suits, the crew performed the final Saturn Workshop closeout, entered the command module, and undocked at 8:55 Gmt. A flyaround of the Saturn Workshop was performed to inspect and photograph it.

Figure 3-13 shows the first crew leaving the command module on the deck of the U.S.S. *Ticonderoga*. Items returned by the crew included exposed film, metal processing and thermal coating samples, and hardware for failure analysis.



Figure 3-13.- First Skylab crew on the deck of U.S.S. *Ticonderoga*.

An overall timeline for the first manned period is shown in figure 3-14.

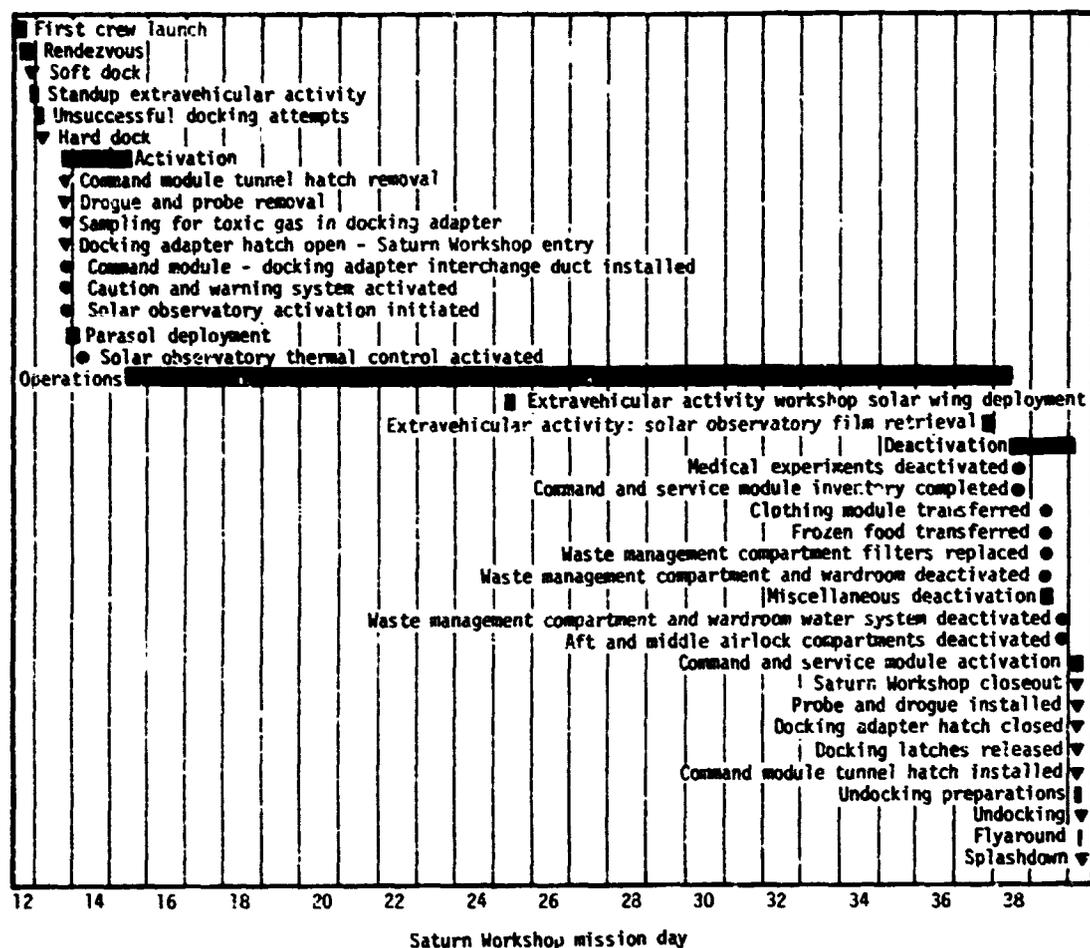


Figure 3-14.- Summary of events of first manned period.

### 3.4 SECOND UNMANNED PERIOD

Following crew departure, depressurization of the Saturn Workshop was initiated to lower the dewpoint to approximately 35°F to prevent condensation in the Saturn Workshop as the internal temperature decreased. The depressurization continued for approximately 6 hours and was terminated at approximately 2 psia. The workshop pressure was allowed to decay to 1.9 psia, which indicated a normal leakage rate throughout the unmanned phase.

The refrigeration system showed an abnormal temperature rise at the time of the first manned period's final closeout. Ground-commanded troubleshooting continued for several hours. The principal activity was cycling between primary and secondary loops and cycling valves. Satisfactory operation was subsequently restored after 2 days.

Solar observatory operations were carried out as planned by ground control until Day 64, when the experiment pointing control primary up-down rate gyro failed. The solar observatory experiment operations were terminated because of

this anomaly. On Day 67 a test was performed using the secondary up-down rate gyro, and operation was satisfactory. To preclude a malfunction, limited solar observatory operations were performed until the next manned period.

The testing of the package of six supplementary rate gyros, called the "six-pack," for installation by the second crew, was already in progress on Day 60. Three units were built in order that parallel development efforts could be carried out. One unit went to the contractor in St. Louis for fit checks on the backup docking adapter and then to Johnson Space Center for crew training. The second unit was undergoing dynamic testing at Marshall Space Flight Center, where the third (flight) unit was also undergoing acceptance testing. The flight unit was completed and shipped to Kennedy Space Center on Day 71, 5 days before launch of the second crew.

An improved version of the parasol thermal shield was developed by Johnson Space Center. The crew trained in the deployment of the new parasol and the twin-pole thermal shield developed by Marshall Space Flight Center. The twin-pole shield had been stowed in the Saturn Workshop by the first crew. The improved parasol was carried by the second crew. Major resupply items for the second manned period were the supplementary rate gyro package and cables, the improved parasol, experiment film, food for a 3-day mission extension, various assemblies to replace failed experiment components, and two laboratory data tape recorders.

About 40 hours before the launch of the second crew, the Saturn Workshop vent valves were commanded open, resulting in final depressurization of the Saturn Workshop down to 0.65 psia. Repressurization began immediately and was terminated at 5 psia approximately 20 hours before launch. A sequence of major events of the second unmanned period is shown in figure 3-15.

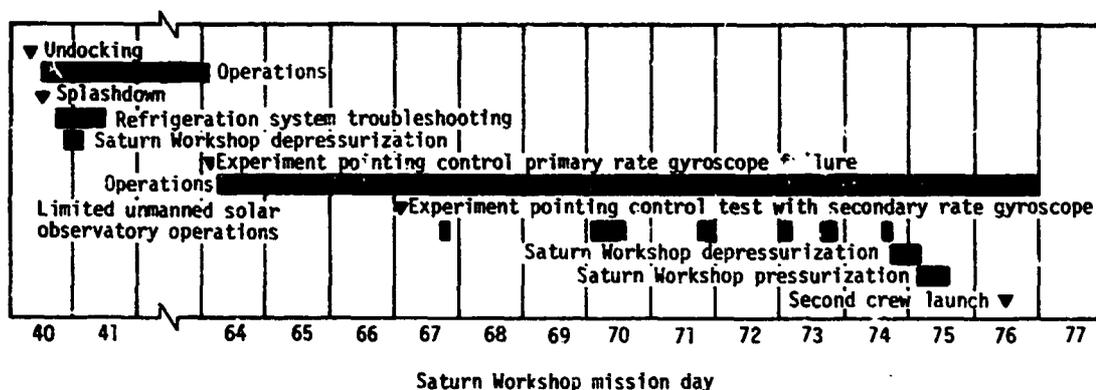


Figure 3-15.- Summary of events of second unmanned period.

### 3.5 SECOND MANNED PERIOD

The second crew was launched at 11:10 Gmt on Day 75 from Launch Complex 39B at Kennedy Space Center. The crew consisted of Captain Alan L. Bean, USN, Commander; Dr. Owen K. Garriott, Science Pilot; and Major Jack R. Lousma, USMC, Pilot. The original plan was to launch the second crew on Day 96. However, because of the degradation of the rate gyros and the possible deterioration of the thermal shield, it was desirable to return as soon as possible. Upon the satisfactory assessment of the flight effects on the first crew, preparation of the launch vehicle, assembly of repair materials, and the completion of necessary

crew training, the crew was launched on Day 76. The second manned period was extended 3 days beyond the planned 56 days to allow more work time and permit a more favorable splashdown area.

### 3.5.1 Activation

Shortly after orbital insertion, the Pilot began to experience motion sickness. He obtained relief by taking one anti-motion-sickness capsule and was able to participate in the activation after docking. Rendezvous was successfully attained and a flyaround inspection was performed. During the flyaround the spacecraft was flown so near the thermal parasol that thruster exhaust impingement caused movement threatening parasol damage. Contamination of the solar cells also was likely, so the inspection was terminated.

Prior to docking, a leak had been detected in the service module reaction control system. Troubleshooting was performed, isolating the problem to quad B. The quad was deactivated for the remainder of the visit.

Docking to the Saturn Workshop was accomplished easily, and the crew entered the vehicle within 2 hours after docking. Activation required more time than was planned when all three crew members developed motion sickness, which slowed their activity. As a result the first extravehicular activity was delayed 6 days, until Day 85. The activation procedures were performed and were similar to those during the first manned period. Additionally, there were several repair and troubleshooting tasks to be accomplished before the schedule of system and experiment operation could begin.

### 3.5.2 Operations

A pressure leak in the condensate dump system occurred soon after activation, causing the system to function improperly. Troubleshooting was unsuccessful in locating the leak. Procedures were modified to collect condensate directly into the workshop storage tank and to vent the storage tank into the workshop waste tank daily. A heated dump probe, which appeared to have an obstruction, was replaced, and the condensate system operated normally. The leak was probably at a quick-disconnect, since during the troubleshooting and probe replacement several quick-disconnects were exercised.

On Day 83 the service module reaction control system quad D was found to be leaking. System pressures and temperatures indicated that oxidizer was venting within the engine housing. The quad was isolated by closing the propellant isolation valves. Plans to use this system for trim maneuvers to establish a repeatable ground track were abandoned. With this second failure of the service module reaction control system, the possibility of terminating the mission was considered. Acceptable control modes and deorbit and entry procedures were defined consistent with the constraints imposed by the two problems. When the decision to proceed with the mission was made, checkout of the rescue launch vehicle and rescue command and service module was initiated in case the command and service module docked to the Saturn Workshop was incapable of returning.

On Day 84 a coolant leak in the primary laboratory coolant loop was indicated by a low pump inlet pressure warning. Ground analysis showed a long term decrease in pressure. The crew performed a visual inspection of the coolant system, looking

for the leak, but no evidence of the coolant fluid was found. On Day 85, during the first extravehicular activity, an inspection was performed outside Skylab to try to locate residue from a coolant leak, but with no success. During this extravehicular activity the Science Pilot and the Pilot, besides inspecting the cooling system, retrieved and replaced film canisters in the solar observatory, deployed the twin-pole thermal shield over the parasol, inspected and repaired the ultraviolet spectrometer, and deployed an experiment to collect interplanetary dust to study its nature and distribution. The extravehicular activity lasted 6.5 hours.

Several unscheduled maintenance tasks were performed inside during the second manned period. Some of these were replacement and electrical continuity tests of the heated water dump probe; disassembly, inspection, and replacement of laboratory tape recorders; removal of four printed-circuit cards inside the video tape recorder; repair of an ergometer pedal; installation of the supplementary rate gyro package in the docking adapter; and tightening of the chain linkage on the articulated mirror system for one of the experiments.

On Day 91 a saturated control gyro resulted in temporary loss of control gyro attitude control. The loss of control occurred during an attempted momentum dump maneuver following two back-to-back Earth observation passes. Automatic switch-over to thruster control regained spacecraft control but resulted in a relatively large (2584 lb-sec) expenditure of thruster propellant.

The pressure in the primary laboratory coolant loop became so low on Day 102 that the pump was shut off. Flight data indicated that the secondary loop was leaking but was still operational and providing the required cooling. Ground support personnel began trying to determine the best method for reservicing the primary loop in orbit. This led to the development of a reservice kit to be carried by the third crew. Carbon dioxide sensor cartridges from the carbon dioxide removal system were returned for analysis to determine whether or not coolant was present. The theory was that the coolant loop leaks were so small that the coolant was evaporating into the laboratory atmosphere as soon as it leaked. Examination of the carbon dioxide sensor cartridges subsequently established this.

The second extravehicular activity was performed on Day 103 to install the cable interconnecting the rate gyros on the solar observatory and the supplementary rate gyro package in the docking adapter, work on solar observatory doors, and retrieve and replace solar observatory film canisters. The extravehicular activity lasted 4.5 hours. The previously installed supplementary rate gyro package was activated and operated successfully. The gyros' alignment was excellent, and no adjustment was necessary. Use of the six new gyros combined with the three best ones from the original nine ended major rate gyro problems for the rest of the mission.

The experimental operations planned for the second manned period were essentially completed. There were 39 passes made with the Earth observation cameras operating and recording data. These passes covered North and South America, Europe, and northwestern Africa. Thruster leak problems in the service module reaction control system precluded the planned trim maneuvers to reestablish the nominal Skylab ground track, which had drifted to the east. Sixty-nine separate television sequences were made of experiments, crew quarters, meal preparation, exercises, demonstrations, etc. A great many Earth terrain photographs and observations were made of hurricanes, tropical storms, volcanoes, cities, water, mountain

ranges, and other items of interest. Figure 3-16 shows a photograph of the Sun in the hydrogen alpha spectrum. A flare can be seen in the center of the picture. The crew held a televised conference from Skylab with reporters at Johnson Space Center.

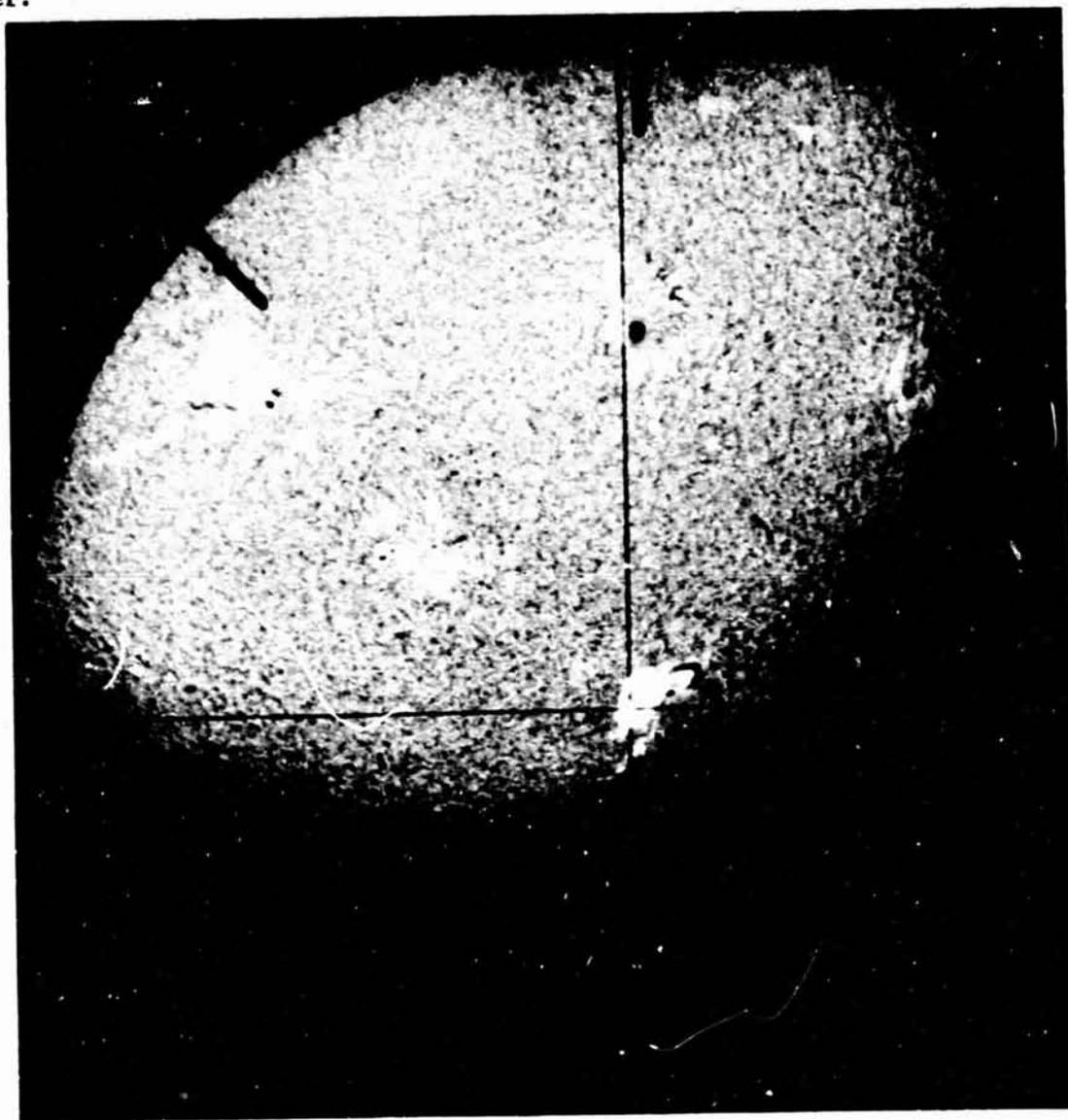


Figure 3-16.- Hydrogen alpha photograph of the Sun.

The +Z scientific airlock was still occupied by the pole from the first thermal shield, prohibiting its use for experiments. A principal instrument used with the scientific airlocks was jettisoned after it would not retract while being used in the -Z scientific airlock. This precluded still other experiments originally planned for these airlocks.

Most of the planned student experiments were accomplished, including recording of the performance of two spiders weaving their webs. A group of six science demonstrations of basic physical principles was performed.

There were three extravehicular activities performed during the second manned period for a total of 13 hours and 43 minutes.

Table 3-IV shows the distribution of manhours for the second manned period. There were 1085 hours spent on experimentation, or 27.7 percent of the time available. This was a 7 percent increase over experiment time in the first manned period.

Table 3-IV.- Manhour Utilization During the Second Manned Period

Activity	Manhours	Percent
Medical experiments	312.5	8.0
Solar observatory experiments	305.1	7.8
Earth observation experiments	223.5	5.7
Corollary and student experiments, and detailed test objectives	243.6	6.2
Sleep, rest, off duty	1224.5	31.2
Pre- and post-sleep activity (2 meals included)	837.6	21.3
Lunch	138.1	3.5
Housekeeping	158.4	4.0
Physical training and personal hygiene	202.2	5.2
Other operations (extravehicular activity, activation and deactivation, television)	279.7	7.1
<b>Total</b>	<b>3925.2</b>	<b>100.0</b>

### 3.5.3 Deactivation

The deactivation of the Saturn Workshop proceeded as scheduled and was similar to that carried out by the first crew. A portable fan was mounted in the docking adapter to circulate air over the supplementary rate gyro package for cooling during the unmanned period. The third extravehicular activity was performed as planned to change solar observatory film and retrieve various experiment samples.

More time than was planned was spent on command and service module activation. The checkout of the service module reaction control system was lengthy to ensure that the system operated satisfactorily. Undocking, on Day 135, was normal and no flyaround of the Saturn Workshop was made because of the problems with the reaction control quads.

An overall timeline for the second manned period is shown in figure 3-17.

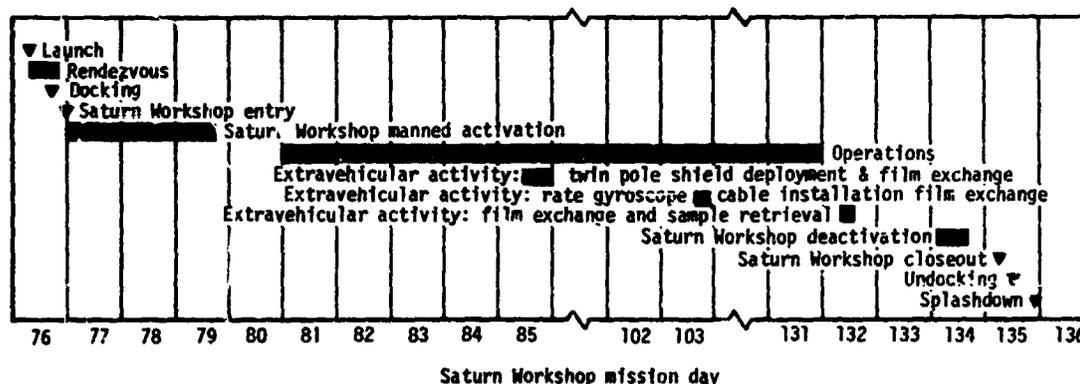


Figure 3-17.- Summary of events of second manned period.

### 3.6 THIRD UNMANNED PERIOD

The launch of the third crew was postponed until November 16 to obtain better and extended viewing of Comet Kohoutek and to plan for extending the visit to 84 days. The final decision on the extension would not be made until about 50 days into the third manned period. Comet Kohoutek was discovered on March 7, 1973, by Dr. Lubos Kohoutek at the Hamburg Observatory. Its approach during the Skylab mission was an unprecedented opportunity.

Work continued on the laboratory coolant loop reservice kit. The prototype kit was completed on Day 121 and was used by the Commander and Pilot of the third crew for training. The kit contained a tank and panel assembly filled with coolant, three short hoses and adapters, repair seals, and valves for connecting to the spacecraft coolant lines. The flight reservice kit underwent testing and acceptance and was at Kennedy Space Center on Day 176 for stowage in the command module.

Analysis of five carbon dioxide sensor cartridges returned with the second crew showed that two contained traces of the coolant. Other tests confirmed that coolant did not harm the filters in the carbon dioxide removal system, that the filters cleaned the atmosphere every 20 hours, and that the coolant would not support combustion. Further, the Johnson Space Center medical directorate confirmed there was no toxicity problem. The primary coolant loop had been shut off on Day 102, and the estimated date for the secondary loop to be depleted was Day 207. The overall conclusion was that it was both safe and mandatory to reservice the primary coolant loop.

On Day 135 the Saturn Workshop was depressurized to 2 psia to lower the dewpoint and was then repressurized to 5 psia with nitrogen to aid in cooling the six gyros in the docking adapter. The pressure decayed at the normal leak rate to 4.05 psia by Day 164. The laboratory was then repressurized to 4.5 psia and again decayed to 3.75 psia on Day 185.

On Day 174 control gyro 1 wheel speed decreased from 9123 to 9060 rpm. The current in one motor winding increased slightly. After 1 hour, the wheel speed and current returned to the normal reading.

Unmanned solar observatory experiments were performed as scheduled until Day 185, when the primary experiment pointing control orbital lock failed to release. Use of the secondary experiment pointing controller permitted normal operations. Data taking for several solar experiments was then curtailed until the crew arrived. One solar observatory experiment continued to operate because it did not use the experiment pointing controller.

On Day 185 the Saturn Workshop's pressure was decreased to 0.7 psia to remove an abnormal mixture of nitrogen and oxygen used for rate gyro cooling. The Saturn Workshop was then repressurized back to 5 psia with the normal mixture of nitrogen and oxygen.

Figure 3-18 is a summary of the events occurring during the third unmanned period.

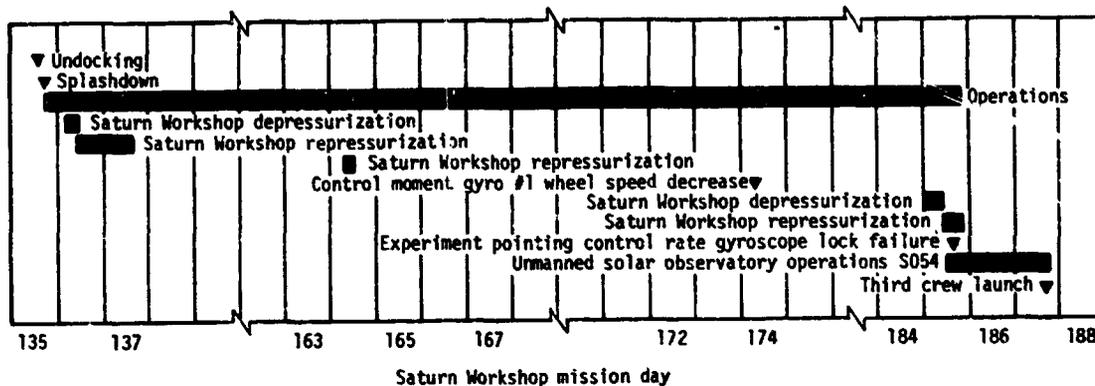


Figure 3-18.- Summary of events of third unmanned period.

### 3.7 THIRD MANNED PERIOD

The command and service module carrying the third crew was launched at 14:01 Gmt on Day 187 from Launch Complex 39B at Kennedy Space Center, on a Saturn IB launch vehicle. The crew consisted of Lieutenant Colonel Gerald P. Carr, USMC, Commander; Edward G. Gibson, Science Pilot; and Colonel William R. Pogue, USAF, Pilot.

The third manned period was originally planned to last 56 days; however, because of the success of the first two manned periods and because the prime viewing times for Comet Kohoutek were around Day 236, the period was extended to 84 days. After the 56-day point was reached the crew was given weekly go-aheads based on medical data sent to the ground and successfully completed an 84-day mission.

#### 3.7.1 Activation

Rendezvous with the Saturn Workshop was accomplished with little difficulty, but three attempts at docking were necessary before a hard dock was achieved. The extension of the manned period and resulting changes in requirements required new equipment to be carried up, so activation of the laboratory was slowed some by the large number of items to be transferred from the command module. Also, the crew experienced "stomach awareness" problems, which slowed their activity somewhat.

On Day 190, as part of the activation sequence, the primary laboratory coolant loop was reserviced and resumed satisfactory operation throughout the rest of the mission. The secondary loop was to be reserviced only if necessary.

#### 3.7.2 Operations

The third manned period was highlighted by the photography of Comet Kohoutek and problems experienced with the control gyros. Extravehicular activities were carried out in a routine manner.

On Day 191 the coolant loop for the solar observatory control and display panel and Earth observation equipment exhibited erratic flowrates. Contamination

was suspected, and on Day 219 the coolant loop filter was replaced with a spare liquid-gas separator. There was some contamination and gas, which the separator removed. New filters were installed and the loop's flowrate returned to normal.

On Day 194 control gyro 1 spin motor current showed a rapid rise, indicating a failure. Motor currents increased from 1 to 2 amperes. Control gyro power was turned off by ground command. This was sensed by the solar observatory digital computer, and a control mode using control gyros 2 and 3 was initiated. On Day 194 the first photographs of Comet Kohoutek were taken. As the comet neared the Sun more time was spent photographing it. The third extravehicular activity, on Day 231, was devoted exclusively to study of the comet and the Sun. Photographs were taken with a special camera brought up with the third crew for that purpose. Photographs were also taken of the comet using the solar observatory instruments and instruments from other experiments.

On Day 206, control gyro 2 began showing signs of irregular operation. This attitude control system situation threatened an early termination to the mission. The gyro symptoms were slightly lower speed and slightly higher temperatures and currents. The gyro would operate abnormally for a period and then would return to proper operation. The periods of abnormal operation became longer as the mission progressed. Throughout the remainder of the mission, ground control closely monitored the operation of control gyro 2. After considerable testing and analysis a decision was made to control the control gyro heaters manually. These heaters maintained the gyro bearings at a constant temperature. At the end of the third manned period, control gyro 2 was still operating in this manner.

During the third manned period 70 television sequences were made of experiments, crew activities, comet observations, science demonstrations, Earth surface features, etc. A large number of Earth terrain photographs and observations were made of volcanoes, rivers, cities, vegetation, ocean currents, Earth faults, and other features. Figure 3-19 shows a picture of Mobile Bay, Alabama, taken with one of the Earth observation cameras. A partial solar eclipse was photographed on Day 225. The third crew held two televised press conferences from Skylab.

There were 45 passes made for Earth observations experiments. There were three maneuvers performed to maintain a repetitive ground track every 5 days for the Earth observations experiments. Most of the planned student experiments were performed, and 17 science demonstrations were performed.

Four extravehicular activities were performed during the third manned period for a total of 22 hours and 13 minutes. During three of the extravehicular activities the crew changed solar observatory film, deployed experiments, pinned solar observatory doors open, and retrieved experiment samples and film. During the other extravehicular activity they photographed Comet Kohoutek.

In addition to reservicing the primary laboratory coolant loop and the solar observatory control and display panel coolant loop, some of the maintenance performed by the crew consisted of replacing solar observatory television monitor 1 in the control and display panel, repairing laboratory tape recorders, replacing an electronic unit in the video tape recorder, and replacing a defective seal in the washcloth squeezer.



Figure 3-19.- Mobile Bay, Alabama, taken with Earth observation camera.

Table 3-V shows the distribution of manhours for the third manned period. There were 1563 hours of experimentation, or 25.8 percent of the time available. This was slightly lower than that obtained during the second manned period.

### 3.7.3 Deactivation

The deactivation proceeded as scheduled and was similar to those previously performed. The Saturn Workshop was configured to make it safe for possible future docking or entry. The extravehicular activity hatch was configured to be opened from the outside in case of a visit by a spacecraft not equipped with the proper docking system. The systems were placed in a mode for revisit without reactivation. A plenum bag with several items, including food and film, was stowed in the docking adapter. It is readily accessible for retrieval by a suited crewman in the event of a possible revisit.

Table 3-V.- Manhour Utilization During  
the Third Manned Period

Activity	Manhours	Percent
Medical experiments	366.7	6.1
Solar observatory experiments	519.0	8.5
Earth observation experiments	274.5	4.5
Corollary and student experiments and detailed test objectives	247.0	4.1
Kohoutek observations	156.0	2.6
Sleep, rest, off duty	1846.5	30.5
Pre- and post-sleep activity (2 meals included)	974.9	16.2
Lunch	409.1	6.8
Housekeeping	298.9	4.9
Physical training and personal hygiene	384.5	6.4
Other operations (extravehicular activity, activation and deactivation, television)	571.4	9.4
<b>Total</b>	<b>6048.5</b>	<b>100.0</b>

After the workshop was closed out and before undocking, the service module reaction control system was used to increase the Saturn Workshop's orbit from 444 by 431 kilometers to 455 by 433 kilometers. This maneuver lasted 180 seconds and resulted in an increase in orbital lifetime of about 1 year. Undocking was normal on Day 271.

An overall timeline for the third manned period is shown in figure 3-20.

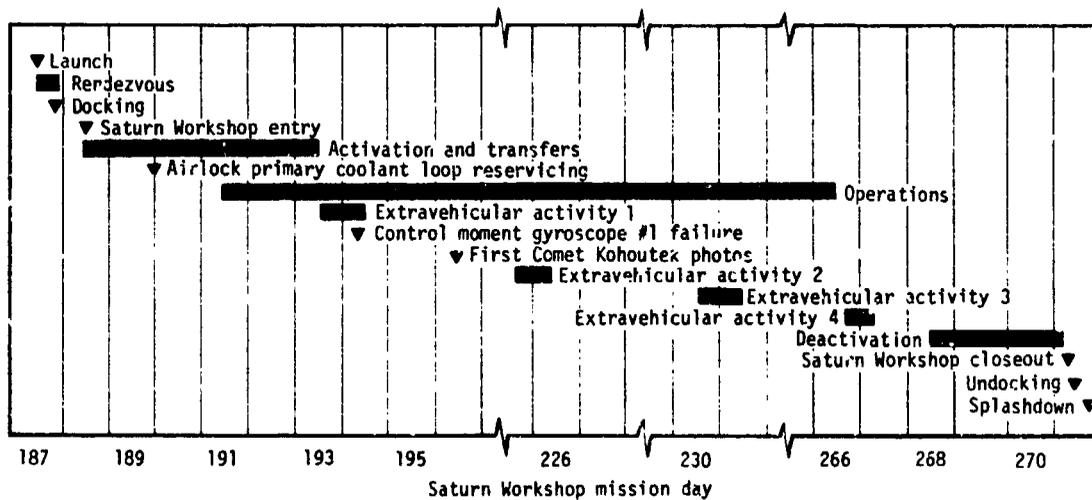


Figure 3-20.- Summary of events of third manned period.

### 3.8 TESTS AND ORBITAL STORAGE

End-of-mission engineering tests began shortly after command and service module undocking on Day 271 and continued for 32 hours before the Saturn Workshop was completely powered down. The internal pressure was decreased to 0.5 psia and was allowed to decay. The engineering tests and the results are shown in table 3-VI.

Table 3-VI.- Summary of Postmission Tests

Tests	Results
Control gyro 1 spinup attempt.	Control gyro 1 wheel did not overcome the bearing friction.
Control gyro 2 and 3 bearing drag tests.	Control gyro 2 was within limits but was slightly higher than normal and gyro 3 was normal.
Laboratory power conditioner battery capacity tests.	Laboratory power conditioner batteries exhibited very little degradation.
Secondary refrigeration system operation and an attempt to get both the primary and secondary loop radiator bypass valves returned to the normal mode of operation.	Cycling of the radiator bypass valves in both the primary and secondary refrigeration system loops failed to return the loops to their original performance.
Rack rate gyro turned on to provide data on the heater control circuits.	The rack rate gyros which exhibited excessive drift rates earlier continued to do so.
Laboratory secondary coolant loop troubleshooting.	Inverter 1 in the laboratory secondary coolant loop had failed.
Operation of the secondary pulse code modulation digital data acquisition system.	Tests on systems which had not previously been used showed the systems to be fully operational.
Operation of the secondary data storage interface unit.	Tests on systems which had not previously been used showed the systems to be fully operational.
Testing of laboratory 10-watt transmitter A.	The failed transmitter did not recover.
Memory load unit test using the program tape.	Tests on systems which had not previously been used showed the systems to be fully operational.
72 kilobits per second uplink test.	Tests on systems which had not previously been used showed the systems to be fully operational.

Digital command from the ground is possible whenever the solar array is receiving sufficient sunlight. It is also possible that a suited crewman could enter and activate systems under the condition that the solar arrays are receiving sunlight. The Saturn Workshop is expected to have an orbital lifetime of about 10 years. This lifetime is estimated by use of a mathematical model that accounts for the ballistic coefficient of the Saturn Workshop--a parameter based on cross-sectional area, mass, and aerodynamic drag coefficient--and the density of the atmosphere, which, at this altitude, is largely dependent upon solar activity. Data were taken during the mission on the levels of solar activity and on changes in the orbit to allow comparison of the mathematical model with the actual conditions. New estimates were made during the mission as the mathematical model was refined and as the ballistic coefficient of the vehicle changed. These are summarized in table 3-VII. The loss of one solar wing changed the cross-sectional

Table 3-VII. Variations in Predicted Values for the Saturn Workshop

	Premission	Mission	Mission end
Ballistic coefficient, kg/m <sup>2</sup>	122	170	207
Predicted lifetime, days	2360	2970	3610

area and the mass from the values used in the premission calculations. The loss of the meteoroid shield also reduced the mass. Other changes which occurred were the expenditure of consumables and velocity changes made to give the desired ground track. At the end of the third manned period the orbital altitude of the Saturn Workshop was increased, using the reaction control thrusters of the command and service module. After the final crew left, the Saturn Workshop was rotated to the gravity-gradient attitude, with the docking adapter away from the Earth and the solar observatory trailing. These two changes affected the final estimate of the orbital lifetime shown in figure 3-21; this estimate reflects the refinements made in the mathematical model and the data obtained on solar activity during the mission.

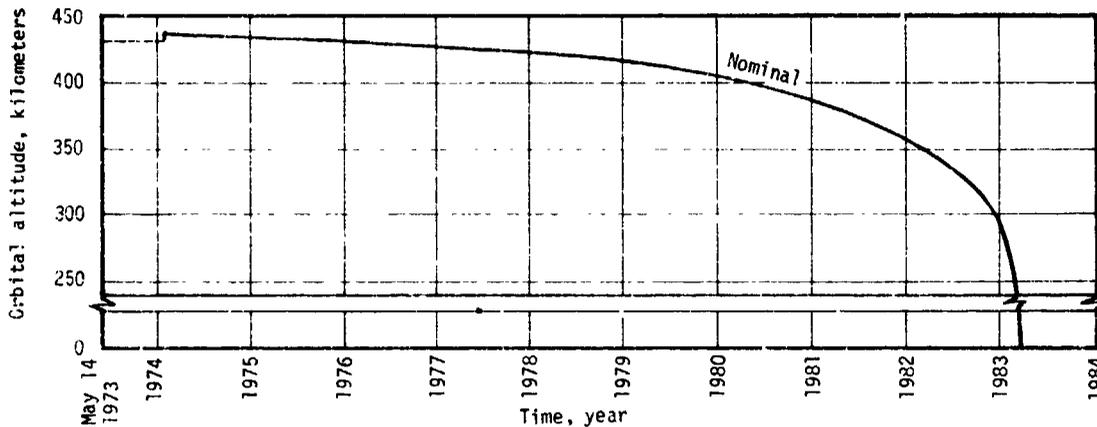


Figure 3-21.- Saturn Workshop predicted orbital decay.

The elements which were jettisoned or lost have much shorter lifetimes; some had already entered the atmosphere within 40 days. The four sections of the shroud have estimated lifetimes varying between 700 and 1000 days, and the predicted lifetime of the lost solar wing is 1500 days.

### 3.9 MISSION OPERATIONS SUPPORT

The Skylab mission was controlled from the Johnson Space Center with Marshall Space Flight Center providing technical support on systems and experiments for which it had development responsibility. An operations-support center was established at Marshall Space Flight Center and was manned by specialized support groups. These groups, consisting of government and contractor personnel, evaluated the performance of the Saturn Workshop systems and experiments. This technical support was provided 24 hours a day and 7 days a week. Additional technical support was also available to the support center from other Marshall personnel, contractor plants, and other agencies.

Real-time and onboard recorded data (taken between ground sites) were received at the remote ground sites, processed by the site for redundancy removal, and transmitted in digital form to Johnson Space Center. Selected data were available for real-time display at both centers. All data on Marshall-developed equipment were then extracted and relayed to the Marshall Space Flight Center. These data were reproduced at low sample rates in data books and in user tapes for routine data analyses. The remote site also generated analog data tapes and retained them for backup transmission system checks, and delivery if required for special purposes.

Figure 3-22 shows engineers at support center consoles monitoring instrumentation displays. More detailed information on the mission support management and data procedures can be found in reference 37.



Figure 3-22.- Engineers monitoring the laboratory instrumentation readouts.

Debriefings from the crews also served as a very useful source of information. These were performed in several modes. Inflight debriefings consisted of both live and recorded conversations, both in response to specific questions and simply to relate observations and experiences. When the crew returned, a series of various types of debriefings continued for approximately 30 days. Transcripts of these debriefings were provided for reference. The postflight debriefings also consisted of response to questions as well as self-debriefings on the several areas of activity. This provided invaluable data for ongoing operations analysis and mission support.

Simulators.- Various simulators were used before and during the mission for procedures development, problem analysis, crew training, and other supporting functions. These proved invaluable to the success of the mission, especially with the problems related to the launch anomaly. Some of the more significant ones are described.

The Marshall neutral buoyancy simulator (a water tank 75 feet in diameter, and 40 feet deep) provided a simulated zero-gravity environment for full-scale trainers and mockups for design evaluations and crew training. Before launch the normal extravehicular activity training was the major function of the simulator. After the launch anomaly, the simulator was used extensively to evaluate potential flight repairs that could be accomplished through extravehicular activity. Two of the more significant repairs were erection of the two thermal shields and deployment of the workshop solar array. More information on the neutral buoyancy simulator can be found in reference 36.

A high-fidelity simulator of the laboratory instrumentation and communications system, including a ground station, was located at St. Louis. This test unit and a solar observatory instrumentation and communications simulator located at Marshall were used to reproduce anomalous conditions and determine applicable corrective action. Prior to launch, the units were used to verify radiofrequency interfaces between the ground tracking stations and the Saturn Workshop, and between the experiments and the data system. During the mission several failures were simulated to determine the cause and corrective action. Some of the items investigated were the laboratory tape recorders, a 10-watt transmitter, a video tape recorder, the multiplexers, a television monitor, and a coaxial switch.

The solar observatory flight backup unit at Marshall was used as a simulator to resolve problems. Tests associated with the X-ray spectrographic telescope verified that it was possible for the crew to move a stuck filter wheel during extravehicular activity and also replace the film magazine with the instrument power on during extravehicular activity. The cause of the thermal shield aperture door failure and the installation of the spectrograph and extreme ultraviolet monitor auxiliary timer were verified.

Satisfactory thermal and environmental control for the Saturn Workshop was made possible by a continuous support effort. Different computer programs were available for analyzing the Saturn Workshop thermal control. Individual systems and components were processed on several computers depending on the complexity of the analysis. These became particularly important after the loss of the meteoroid shield.

Many simulators were used in the design and verification of the attitude and pointing control system. Seventeen variations were used, ranging from full software modeling of the overall system to simulators which used actual hardware wherever possible. Six of these simulators were developed and used at Marshall, including one which used flight-type hardware and software. The other simulators were developed and used at various contractor facilities. These simulators were developed to verify system operation and were available through the mission for problem diagnosis. One model used extensively late in the mission simulated thruster firings for given maneuvers and recorded gas used. This simulator proved valuable when one control gyro failed, putting a greater demand on the thruster gas. With the aid of this model, timing rates of vehicle maneuvers were carefully planned to minimize thruster firings so that Earth observations could continue and meet experiment objectives.

Two simulators were used to support analysis of the Skylab electrical power system before and during the mission. A computer program was developed for simulation of the electrical power system performance over a wide range of operating

conditions and environments. The program was used on a daily basis during the mission, particularly in the analysis of proposed Z local vertical and quasi-inertial attitude modes. It was also used on an around-the-clock basis during the critical period following the launch of the Saturn Workshop. The program proved to be extremely valuable in mission profile analysis and power management. The power system simulator located at Marshall consisted of flight-type power equipment except for solar arrays, which were simulated. In addition to pre-mission checkout and verification tests, the simulator was used to provide hardware and power system theory indoctrination and experience for the flight controllers and the flight crews. During the mission, the simulator provided continuous support during activation and deactivation periods as well as during periods when anomalous flight conditions imposed close monitoring and verification of hardware performance. One major support effort was the verification that the laboratory batteries could successfully survive the abnormal extended storage imposed early in the mission.

High fidelity mockups of all the modules were available for fit, function, and other purposes. Backup flight modules were also available, as well as numerous components for mission period tests and simulations, storage analysis, and other operations support functions.

### 3.10 PERFORMANCE SUMMARY AND CONCLUSIONS

The overall performance of the Saturn Workshop was very satisfactory, and several conclusions can be drawn from the results of data evaluation. Some systems experienced difficulties; however, through redundant loops, workarounds, maintenance, and repairs, the objectives of the mission were accomplished and exceeded in most cases.

The primary structure of the Saturn Workshop withstood the loads encountered during powered flight and throughout the mission without any evidence of deformation or unusual stresses. The only serious structural problems were the loss of the workshop's meteoroid shield during launch and the subsequent loss of a solar array wing because of the premature deployment of the meteoroid shield. There were a few unexplainable structural noises and vibrations in orbit, but they caused no problems. The deployment sequence to convert from the launch configuration to the orbital configuration was completed as planned with the exception of the meteoroid shield and the workshop solar arrays. Leakage of laboratory atmosphere was much less than design specifications allowed. There were problems with the operation of the solar observatory experiment external aperture doors, but operational or maintenance procedures permitted continuation of the experiments.

The instrumentation and communications systems performed satisfactorily during the mission, although some problems occurred. There were some minor problems in the audio subsystem with feedback, noise, and component failures. Modified operational procedures and replacement with spare units enabled continued use of the subsystem. None of these problems interfered with crew operations. There were several problems with the television subsystem, but these were solved by in-orbit repair or by replacement of equipment with spares. The portable television camera for external viewing of Skylab was not deployed because the parasol thermal shield occupied the +Z scientific airlock and there was little viewing required in the -Z area. The deployment mechanism became inoperative and was jettisoned on Day 83.

The operation of the command subsystem was satisfactory, and the flexibility designed into the system proved adequate when major attitude control problems had to be solved. The data subsystem performance was satisfactory except for several problems involving the transmitters and signal processing components which resulted in slightly reduced data and transmission capabilities. The caution and warning subsystem operated satisfactorily, informing the crew of impending problems and allowing proper reaction times to correct them. The rendezvous and ranging subsystem was operated for each command and service module docking and provided acquisition of the Saturn Workshop at ranges exceeding specifications.

Attitude control of the Saturn Workshop was transferred from the instrument unit to the Saturn Workshop attitude control system as planned, with no problems. The system performed maneuvers and attitude stabilization throughout the mission. The use of large momentum storage gyros for attitude control and maneuvering against gravity gradient torque to manage these gyros' momentum was successfully proven for the first time. Maneuvers were smooth and accurate; however, this did take time away from stabilized experiment activities. The flexibility of the system contributed to the success of the mission. The system was designed with in-orbit reprogramming capability and extensive automatic redundancy management. The digital computer control programs were revised to meet new mission objectives. As an example, a technique was developed to refine the solar observatory pointing system for Comet Kohoutek. This technique was implemented in the third manned period.

The thruster attitude control system performed properly throughout the expanded mission. During the first unmanned period, after the loss of the meteoroid shield, a large amount of propellant was used to maneuver the vehicle to the attitude which kept the laboratory internal temperatures and electrical power at an acceptable level. The loss of a control gyro during the third manned period reduced the control momentum storage capability, necessitating a larger amount of thruster control and propellant usage than had been anticipated. However, the propellant supply was ample to provide the required control throughout the mission period with a reserve for contingency operation.

Marginal performances and several failures occurred early in the mission in rate gyro processors. The control system had sufficient built-in redundancy available, and by selecting other gyros the system was able to satisfy all the imposed maneuver requirements. As the mission progressed, the gyros were augmented by a supplementary rate gyro package, containing modified gyros, which was carried up and installed by the second crew. After augmentation the rate-sensing system performed well.

The solar observatory experiment pointing control system performed better than expected. The system experienced several minor problems, but the loss of data was minimal.

The electrical power system for the Saturn Workshop operated satisfactorily throughout the mission, in spite of the loss of one workshop solar array wing. Because of reduced power, management of the electrical loads was necessary throughout the mission. The two independent Saturn Workshop power systems were designed to be operated in parallel. This permitted sharing of power in either direction and provided the required flexibility of the power system throughout the entire mission and particularly until workshop solar array wing deployment. The power distribution system experienced a problem when one of the television power buses

short-circuited. A redundant television power bus was used for the remainder of the mission. There were some minor problems with the solar observatory power conditioners and batteries, but none of these interfered with the management of the power system. Ground test procedures used with the solar observatory batteries resulted in the launch of batteries having undetected, premature degradation of capacity. Despite this, the batteries performed satisfactorily. The solar arrays worked properly and the solar cell deterioration was less than expected.

Much of the capability for passive thermal control in the workshop was lost when the meteoroid shield was torn off. The resulting high temperatures were brought under control only when the parasol thermal shield was deployed on Day 14. After the Saturn Workshop was activated and the workshop shielded, temperatures throughout the laboratory remained within the specified range. The electric heaters developed no problems, and the few problems associated with mechanical components in the coolant loop were corrected. There was an unexplained loss of coolant, and the third crew replenished the supply of coolant. The refrigeration system failed to maintain the specified temperature for a short time, but the problem was cleared up before the effects became significant. The coolant system for the controls and displays used for operating the instruments in the solar observatory developed some minor problems that did not interfere with the collection of data.

The environmental life support system operated satisfactorily throughout the mission. The supply of nitrogen and oxygen was more than adequate, despite some unplanned laboratory atmosphere purges with nitrogen deemed necessary because of the possibility of toxic gases during the first days of the mission. There were some minor problems with valves, leakage, and the condensate dump system, but none of these interfered with crew operations. Some crewmen thought that the humidity was too low. Others would have preferred ways to control air flow in areas where there were no duct outlets, but overall atmospheric circulation was good.

The crew systems provisions were generally satisfactory. There were a few problems with the operation of supporting equipment, such as the washcloth squeezer, water heater, shower blower, trash airlock, and water dispenser, but these did not interfere with the mission or crew comfort. All crews preferred the orientation in the workshop, with floors, walls, and ceilings, to the cylindrical arrangement in other parts of the laboratory. The water supply and management were satisfactory. Disposal of trash and wastes was handled satisfactorily, although there were some minor problems in the systems. Sleep provisions caused minor annoyance to some crewmen, but this seemed to result mostly from individual physiological differences or preferences. More handholds would have been helpful in the areas away from the work stations. Crewmen usually pushed off and drifted to the target spot, and they needed rigid restraints or projections for changing direction. Lighting throughout the laboratory was adequate for most purposes, but crewmen needed brighter light for precise maintenance tasks and for reading. Crewmen also recommended a number of improvements to control and display layouts. Extravehicular activity operations were highly satisfactory. Inflight maintenance operations far exceeded premission planning and showed that there are few limitations to repairs that could be accomplished in orbit.

The quantity of contaminants induced by Skylab in its surrounding environment resulted in a background brightness level that was higher than predicted. However,

the steady-state level was maintained below the threshold sensitivity levels of the experiments while data was being taken. Deposition on quartz crystal microbalances with Skylab surfaces in their field of view is believed to be the results of outgassing and service module engine firings. Measured deposition correlated closely with the premission math model predictions as updated for the configuration change of the added thermal shield, and docking and fly-around effects. There was no contamination effect on some experiments, while the effect on others associated with anomalous contamination conditions will not be known until the experiment results are completed. White thermal coatings on surfaces turned to a tan-brown color, and the role of contamination in this is still under investigation. Solar array power showed no discernible degradation due to contamination. The star tracker apparently tracked contaminant particles until changes in operational procedures eliminated this problem. In general, the contamination control incorporated into the Saturn Workshop design and Skylab mission procedures appears to have been effective.

The performance of experiments, with few exceptions, was as planned or better than expected. Some equipment problems were experienced and some crew time was diverted for various reasons; however, the efficiency of the crew and the extension of the mission more than compensated for the time lost. The majority of the student experiments and science demonstrations planned were successfully completed. The integration of the equipment associated with the life science experiments functioned satisfactorily and provided necessary medical data to establish confidence that crews could perform without detriment to their health.

Every solar observatory experiment had some type of difficulty associated with it; however, no problem rendered experiment equipment inoperative. Three of the astrophysics experiments had to be relocated outside Skylab because the +Z scientific airlock was occupied by the thermal shield support. Data were obtained from all of these experiments by use of alternate procedures or by repair or replacement of failed items.

Viewing requirements for Comet Kohoutek were established before the beginning of the third manned period. Most of the instruments used to photograph the comet were already on Skylab, and new procedures were developed for data recording. One extravehicular activity was devoted to photographing Comet Kohoutek. There were no problems with the experiments, and most of the planned objectives were met.

The materials and manufacturing experiments met all premission requirements. Returned specimens from the metals processing experiments were so impressive that it was decided to resupply more samples for the third manned period. The procedures and methods of investigation were changed to give more data.

### 3.11 ACCOMPLISHMENTS

Tables 3-VIII and 3-IX summarize the accomplishments and results of the mission. The manned flight time and the time spent on experiments and extravehicular activity exceeded the accumulated totals of all of the world's previous manned space flights. The number of revolutions and the orbital path permitted close viewing of that 75 percent of the Earth's surface which contains 90 percent of the human population. The solar observatory accumulated over 941 hours of solar viewing and included periods of many and diverse solar activities.

Table 3-VIII.- Mission Summary

Crews				Totals
Commander	Charles Conrad, Jr.	Alan L. Bean	Gerald P. Carr	
Pilot	Paul J. Meitz	Jack R. Lousma	William R. Pogue	
Scientist pilot	Joseph P. Kerwin	Owen K. Garriott	Edward G. Gibson	
Launches	May 25, 1973, 9:00 AM Edt	July 28, 1973, 7:11 AM Edt	November 16, 1973, 9:01 AM Est	
Recoveries	June 22, 1973, 9:49 AM Edt	September 25, 1973, 6:19 PM Edt	February 8, 1974, 11:17 AM Edt	
Launch vehicle (crew)	Saturn IB			
Launch vehicle (Saturn Workshop)	Saturn V May 14, 1973, 1:30 PM Edt			
Orbital altitude	Approximately 435 kilometers			
Orbital inclination	50 degrees			
Orbital period	Approximately 93 minutes			
Orbital distance	26,575 miles			
Distance traveled (sanned)	11.5 million miles	24.5 million miles	34.5 million miles	70.5 million miles
Manned periods	28 days, 49 minutes	59 days, 11 hours, 9 minutes	84 days, 1 hour, 15 minutes	171 days, 13 hours, 14 minutes
Number of revolutions (manned)	404	858	1214	2476
Extravehicular activities				
Stand up (command and service module)	May 25, 1973, 37 minutes			
1	Jr 7, 1973, 3 hours, 30 minutes	August 6, 1973, 6 hours, 29 minutes	November 22, 1973, 6 hours, 33 minutes	
2	June 19, 1973, 1 hour, 44 minutes	August 24, 1973, 4 hours, 30 minutes	December 25, 1973, 7 hours, 1 minute	
3		September 22, 1973, 2 hours, 45 minutes	December 29, 1973, 3 hours, 28 minutes	
4			February 3, 1974, 2 hours, 19 minutes	
Totals	5 hours, 41 minutes	13 hours, 44 minutes	22 hours, 21 minutes	41 hours, 46 minutes

Table 3-IX.- Experiment Summary

Experiment group	Manhours				Number of investigations		
	Crew 1	Crew 2	Crew 3	Total	Planned	Actual	Percent deviation
Solar physics *	117.2	305.1	519.0	941.3	890†	941†	7.1
Astrophysics	36.6	103.8	133.8	274.2	168	345	105
Earth observation **	71.4	223.5	274.5	569.4	62	99	60
Life science	145.3	312.5	366.7	824.5	701	922	32
Engineering and technology	12.1	117.4	83.0	212.5	264	245	-3.4
Materials science and manufacturing in space	5.9	8.4	15.4	29.7	10	32	220
Student	3.7	10.8	14.8	29.3	44	52	18
Totals	392.2	1081.5	1407.2	2880.9	Manhours		
* Film, frames	28,739	24,942	73,366	127,047			
** Film, frames	9,846	16,800	19,400	46,046			
Magnetic tape, feet	45,000	93,600	100,000	238,600			

The capability to conduct longer manned missions was conclusively demonstrated by the good health of the third crew after they had stayed in space for 84 days. The effectiveness of the crews exceeded all premission expectations. Their ability to perform complex repair tasks was instrumental in recovering the full mission capability, and also contributed greatly to fulfilling planned operations throughout the extended period. They exceeded the operational and experimental requirements placed upon them by the premission flight plan in addition to overcoming the numerous problems encountered. The third crew performed a number of scientific investigations and demonstrations not initially scheduled, including the Comet Kohoutek study and several science demonstrations.

The Skylab operation was a spectacular success. It marks the transition from the exploration to the exploitation of this vantage point for the benefit of mankind. The vast achievements of the mission will be unfolding for a long time, yielding new knowledge in technology as well as its application. The experience and documented results will serve as a logical stepping stone to missions of the future.

## SECTION 4

### STRUCTURES AND MECHANISMS

Structures are divided into three parts, primary or load bearing structures, secondary structures, and pressure vessels. Evaluation of all these is limited because instrumentation was not installed for this purpose. The performances of the deployment mechanisms and the solar observatory doors are included here. The mechanical devices which are an integral part of a system are described and evaluated with that system. Additional information concerning the structural system and all the mechanical equipment is contained in reference 10.

#### 4.1 STRUCTURES

Structural elements of the Saturn Workshop must satisfy several requirements. The structure must withstand all loads encountered during prelaunch handling, launch, ascent, deployment, attitude changes, docking, and other activities in orbit. Maximum loads, in most cases, occur during launch. Engine thrust produces compressive loads over the whole length of the vehicle, and gimbaling the engines generates bending loads. Aerodynamic forces resulting from the flow field around the vehicle produce additional compressive and bending loads. Tensile and shear loads result from local reactions. Superimposed on these are vibration and acoustic loads. The structure must also provide radiation protection and a pressure-tight enclosure for the laboratory with a very low probability of micrometeoroid penetration.

##### 4.1.1 Primary Structures

The major elements of the Saturn Workshop (fig. 2-1) are subjected to different loads, and the design of each takes into account the critical load or combination of loads it carries. During launch the shroud is subjected to aerodynamic loads and the effects of acceleration upon its own mass, and also carries part of the load produced by the solar observatory during acceleration. The aerodynamic loads predominate on the greater part of the structure, producing compressive loads and bending loads due to the angle of attack resulting from the launch vehicle pitch program. Generally, the critical condition occurs when the product of dynamic pressure and the vehicle angle of attack reaches its maximum value. Other loads that act on the shroud govern in limited regions but impose no additional requirements on the basic structure.

The solar observatory consists of the canister, which is a cylinder containing instruments; the spar, which is a cruciform supporting structure inside the canister; and the rack, which is an assembly of trusses surrounding the canister. The rack transmits loads from equipment mounted on the rack, solar arrays, and canister either to the shroud or to the supporting truss, which is the permanent structural link between the solar observatory and the airlock trusses. A critical load on the rack occurs at the time of first-stage separation. The supporting truss carries a part of the loads during ascent and reacts to various forces during deployment of the solar observatory. Another critical load occurs during docking because of the large moment associated with the offset mass of the solar observatory.

The docking adapter is subjected only to inertial loads during launch, since it is surrounded by the shroud. The largest loads are the impact loads that occur during docking. Loads acting on the docking adapter are transmitted to the structural transition section and through this to the airlock trusses, which also support the airlock, solar observatory, nitrogen storage tanks, batteries, and other components. The inertial load associated with maximum acceleration is critical for both the structural transition section and the airlock trusses. These loads, as well as the shroud loads, are transferred to the fixed airlock shroud, and from there to the instrument unit structure. The combined load reaches its highest value at the time of maximum acceleration. Loads other than those due to internal pressure or reactions are transmitted from the instrument unit to the forward skirt of the workshop, through the cylindrical section of the tank to the aft skirt, and from there to the launch vehicle interstage. In addition to compressive and bending loads carried through the instrument unit, the workshop must carry its own inertial and aerodynamic loads, and it must withstand the internal pressure necessary to give structural stability to the cylindrical section. The effects of bending predominate, and the maximum aerodynamic load during ascent establishes the critical design load for the workshop.

Only limited data are available for quantitative verification, but the integrity of the Saturn Workshop's primary structures was demonstrated by successful performance. Data from sensors on the Saturn Workshop and launch vehicle showed strong disturbances when the meteoroid shield was lost; a rate-sensing gyroscope indicated a clockwise rotation with a maximum rate of 3 deg/sec, and an accelerometer showed a shock with a maximum amplitude of 17.2 g's. Although these values exceeded the design criteria, calculations based on data obtained from the launch vehicle indicated that structural design loads of major components were not exceeded. No evidence of yielding was reported by the crews, nor is any apparent in photographs taken from the command module. There were no data on internal sound levels. External sound-pressure levels during launch were less severe than had been expected. Low-frequency vibration data from two points in the Saturn Workshop showed no significant effects on the structure.

#### 4.1.2 Pressure Vessels

Except for the workshop, the laboratory is designed to operate at 5 psi and withstand a bursting pressure of 6.2 psi. To provide added rigidity and strength at launch, the workshop is pressurized to between 23 and 26 psia. The airlock and docking adapter are at ambient pressure at launch and are vented during ascent. The internal pressure in orbit reached a maximum value of 5.8 psia when experiments were conducted with the maneuvering unit during the third manned period. In addition to withstanding internal pressure, the structure must also control leakage of the internal atmosphere. At 5 psia and 70°F, the leakage rate allowable by design for the Saturn Workshop is 14.7 lb/day, but the average rate during the mission was only approximately 3 lb/day.

The laboratory pressure vessel also provides the primary radiation protection. In-orbit measurements in the airlock showed the average internal radiation to be about 0.1 rad/day, well below the design limit of 0.6 rad/day.

A number of pressure vessels were required to store the gases needed to supply the atmosphere and to meet other demands. Six 57 ft<sup>3</sup> cylindrical tanks inside the fixed airlock shroud (fig. 4-1) contain oxygen at ambient temperature and at an initial pressure of about 3000 psia. Six 19.3 ft<sup>3</sup> spherical tanks on the airlock trusses (fig. 4-2) contain nitrogen, also at ambient temperature and at about 3000 psia. These tanks furnish gas for the internal atmosphere and for

- |                                  |  |
|----------------------------------|--|
| A. Molecular sieves              | E. Fixed airlock shroud                  |
| B. Structural transition section | F. Airlock hatch                         |
| C. Oxygen tanks                  | G. Handrails                             |
| D. Nitrogen tanks                | H. Electrical control and display panels |

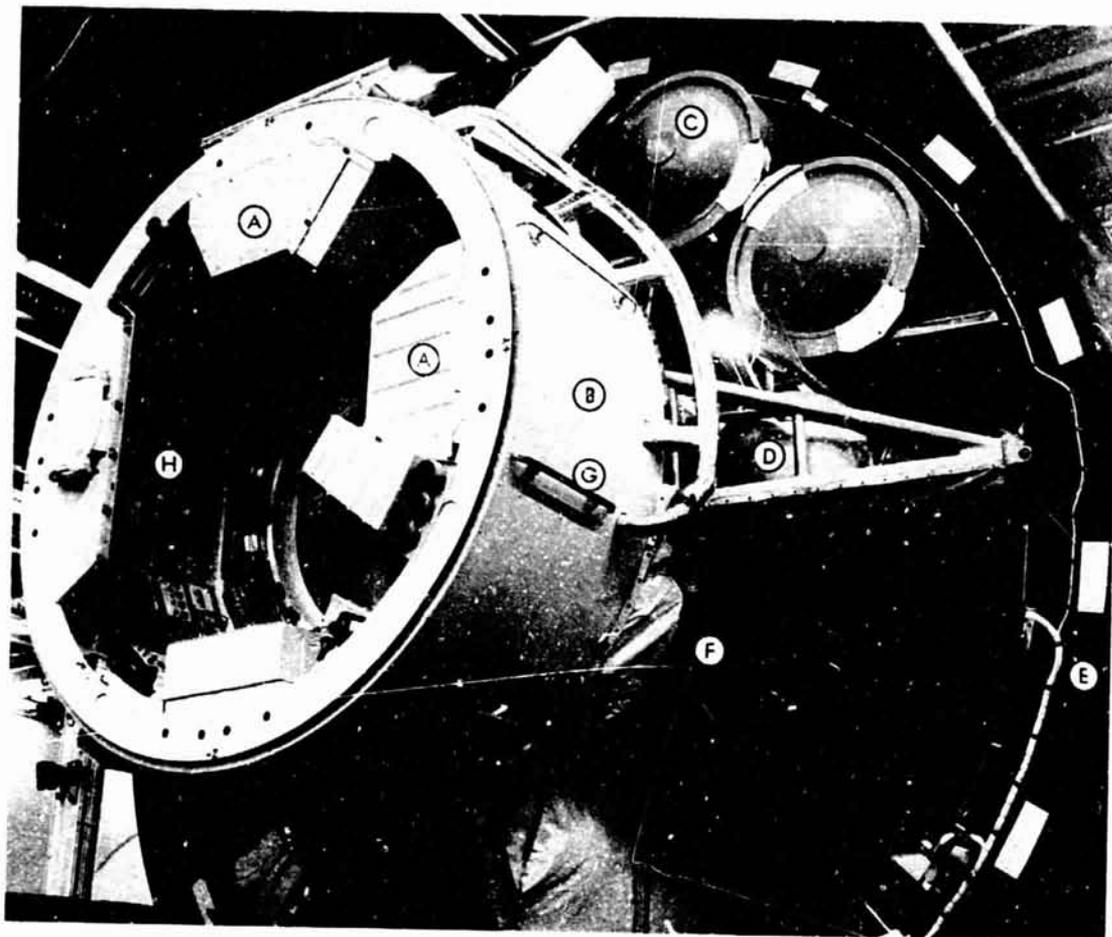


Figure 4-1.- Fixed airlock shroud and oxygen tanks.

other functions in the laboratory. At the aft end of the workshop are 23 spherical tanks, each 4.5 ft<sup>3</sup>, containing nitrogen at ambient temperature and initially at about 3200 psia. One of these supplies high-pressure gas to operate several deployment mechanisms, and is vented after these functions are completed. The others supply propellant to the attitude control thrusters. None of the tanks failed structurally, although two tanks exceeded operating pressure limits and one tank exceeded qualification test temperatures. Neither the tanks nor the associated tubing exhibited any detectable leakage.

#### 4.1.3 Secondary Structures

Windows.- The Saturn Workshop has 12 windows for photography and data collection in connection with experiments, crew observation during extravehicular activity, and general viewing during off-duty periods. They must maintain structural integrity and leak-tightness after exposure to shock, vibration, acoustics, pressure, temperature extremes, ionizing radiation, and impacts by micrometeoroids or crewmen.

- |                                  |                            |
|----------------------------------|----------------------------|
| A. Nitrogen bottles              | D. Truss assembly          |
| B. Structural transition section | E. Ventilation fan housing |
| C. Electronic modules            | F. Extravehicular hatch    |

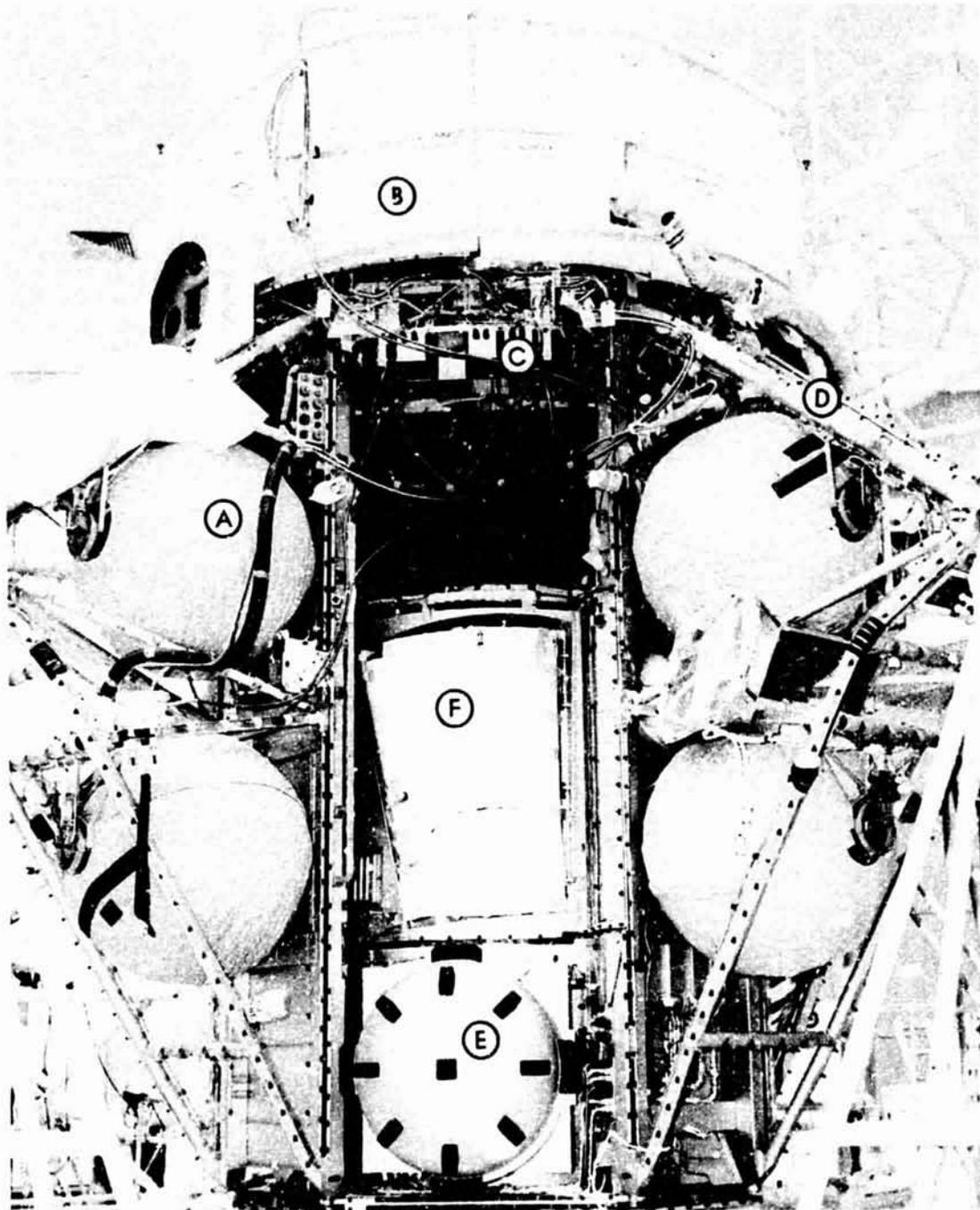


Figure 4-2.- Airlock truss and storage bottles.

The docking adapter contains four windows for conducting Earth observations, all mounted in aluminum frames which carry all flight loads except pressure. The multispectral photography experiment window (fig. 4-3) is a single 18- by 23-inch pane of borosilicate glass 1.6 inches thick, installed near the radial docking

port. It is of high optical quality to prevent degradation of data. The window is supported by a spring system so that vehicle distortions do not induce flight loads into the glass. External and internal covers protect the surfaces from micrometeoroid impacts, contamination, and internal impacts. The external window cover is operated mechanically from inside, and external insulation minimizes heat loss. The infrared spectrometer experiment window is borosilicate crown glass, 3.96 inches in diameter and 0.48 inch thick. The two multispectral scanner experiment windows are 3 inches in diameter and 0.25 inch thick. One is made of germanium and the other of fused silica. The external cover for these is part of the experiment equipment. All four windows were structurally satisfactory throughout the mission, and the crewmen had no adverse comments. The multispectral photography window cover mechanism was operated in orbit for 100 cycles without any problem.

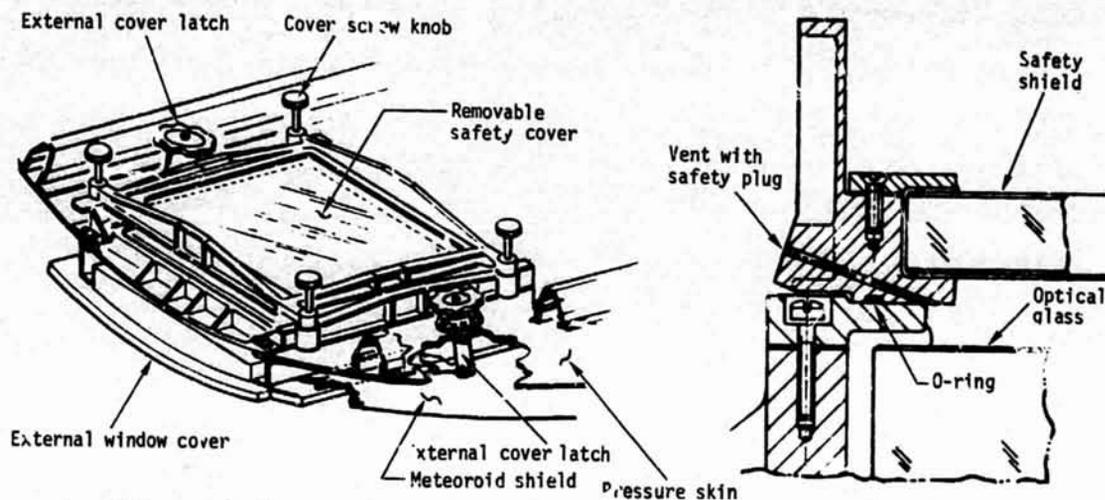


Figure 4-3.- Multispectral photography experiment window.

There are seven windows in the airlock: four oval windows, 8 by 12 inches, spaced at intervals of 90 degrees around the aft part of the structural transition section; two windows, 8.5 inches in diameter, one in each of the airlock's internal hatches; and one window in the extravehicular activity hatch. All seven windows are double-glazed, and the five windows for external viewing have valves for venting the space between the panes. The windows in the structural transition section are protected externally by sliding plastic-laminated fiber-glass covers operated by internal crank assemblies which are locked by quick-release pins. The external pane of each window is Vycor glass, 0.42 inch thick, and the internal pane is tempered glass, 0.24 inch thick. The panes are 0.25 inch apart and are individually sealed to preclude atmospheric leakage. Each window has a valve for venting the cavity between the panes. The windows' size and shape were adequate, although external structure interfered with some photographic usage. Fogging on the inside of the windows facing the Earth occurred after 3 to 4 hours' exposure with the covers open. When the covers were closed, the fog would disappear in 2 to 3 hours. Small fluctuations in internal pressure and in the temperature of the window could have caused the cavity to breathe through the vent valve. Moisture-laden gas entering the cavity in this manner most likely caused the fogging. No fogging was observed on windows facing the Sun. The window cover mechanisms became increasingly harder to operate as the mission progressed, but there were no failures. The windows in the internal hatches are covered by protective mesh on either side. These windows have no

cavity bleed valves and showed no signs of fogging. Their size was considered adequate, and the windows were structurally satisfactory. The window in the extravehicular hatch is identical to the hatch windows used in the Gemini program except for the addition of a vent valve and ultraviolet and infrared coatings. The stowed cover was installed over this window by the first crew and the window was never used.

The wardroom window (fig. 4-4) allows photography and observation by the crew. It is about 18 inches in diameter and consists of two panes of fused silica. The inner pane is heated to prevent condensation from the atmosphere of the Saturn Workshop. The space between the panes was filled with dry nitrogen during fabrication. A removable metal cover fits over the window on the inside to protect the window against bursting pressure during launch and ascent and is put over the window for unmanned periods as a precaution. The window has a shade to shut out light and a transparent shield to protect the window when it is not being used for photography. The window met all functional requirements except for recurring condensation in the space between the panes (11.4.5).

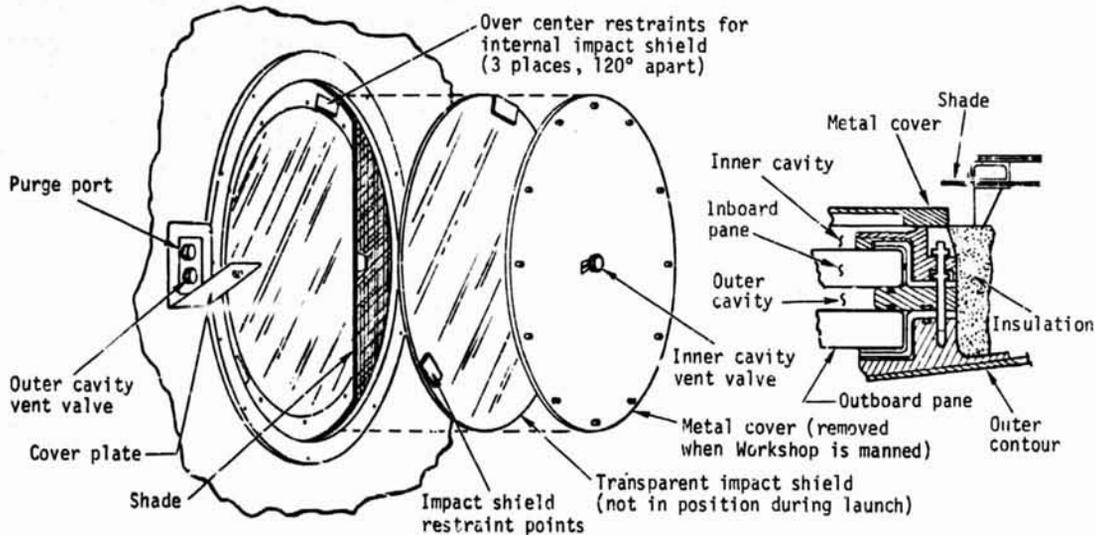


Figure 4-4.- Wardroom window.

**Hatches.** The docking adapter has a circular, inward-opening hatch (fig. 4-5) at each docking port. The hatches are 32 inches in diameter and 1.2 inches thick. Each is held in the closed position by six over-center latches linked to a central shaft. Handles attached to the shaft on both sides of the hatch allow opening and closing from either side. A launch lock, which can be locked only from the outside but can be unlocked from either side, restrains the handle in the closed position at launch and during unmanned periods. A lip on the edge of the hatch depresses a silicone rubber seal in the docking ring to furnish a pressure-tight closure. Six mechanical stops limit the depth the seal is depressed to prevent overstressing it. Each hatch has a differential-pressure gage and a pressure-equalization valve. The hatch at the axial docking port was opened and closed three times during the mission, and no problems were reported with operations. The emergency radial hatch was not used.

The design of the extravehicular activity hatch in the airlock originated in the Gemini program. For use in the Saturn Workshop the original ratchet handle is replaced with a single-stroke handle having a positive lock to hold it closed. To keep the hatch from opening fully before the pressure is equal on

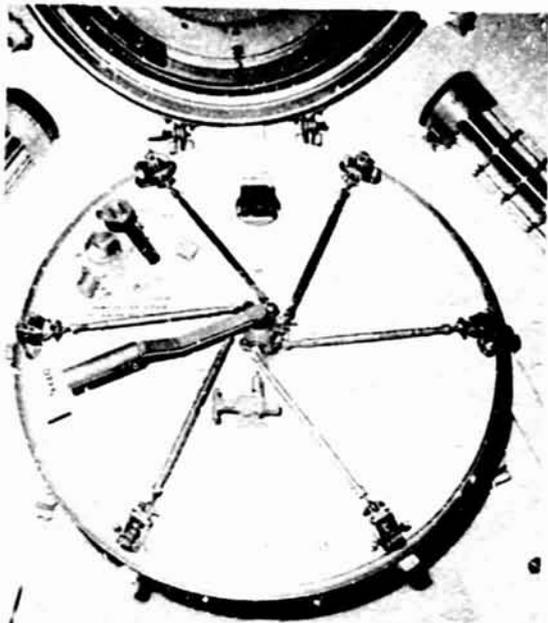


Figure 4-5.- Docking adapter hatch.

both sides, there is also a latch which is designed to hold the hatch in a slightly open position until it is released by the crewman. This latch failed to restrain the hatch as it was being opened, although it held as the hatch was closed. Apparently, the initial movement of the hatch was so rapid that the latch did not have time to engage. Failure of the latch to engage presented no operational problems. The hatch was used eight times during the mission. Operation was reported to be essentially the same as on the training simulator, and the size was adequate for crewmen and equipment.

At each intermediate bulkhead at the ends of the lock section of the airlock are circular hatches, 49.5 inches in diameter. Each hatch is hinged so that it folds along the wall to open, where it is held by Velcro straps. Silicone rubber seals bonded into grooves around the openings in the bulkheads prevent leakage when

the hatches are closed. The latching mechanism is attached to the bulkhead. A single-stroke handle pulls a cable which drives nine latch assemblies to lock or unlock the hatch. The forward hatch was opened nine times and closed eight times. The first crew opened the aft hatch and fixed it in that position. It remained open for the rest of the mission, and the hatch in the forward dome of the workshop was closed during extravehicular activities. This provided more space in the lock tunnel for preparation for extravehicular activity. The crewmen reported that the hatches were easier to operate than those in the training simulators.

There are identical pressure-equalization valves in each internal hatch and in the wall adjacent to the extravehicular activity hatch. The equalization valves in the forward hatch and beside the extravehicular activity hatch were each cycled eight times with no malfunctions. Ice formed on the screen over the inlet to the valve beside the extravehicular activity hatch, restricting gas flow during depressurization. The second crew carried a modified valve cap which had been fitted with a screen. Placing this cap over the valve reduced the time required for depressurization, since ice crystals formed only near the center of the screen, leaving the outer part clear for gas flow. The cap was removed when the pressure decreased to about 1 psia.

A circular hatch approximately 40 inches in diameter closes off the workshop when necessary. When closed, the hatch is locked by 12 ramp-roller devices connected by struts to a central hub. The hatch is opened by rotating a handle attached to this hub. As the handle is rotated, it first reaches an "equalize-pressure" position. This uncovers nine holes, 0.25 inch in diameter, through which gas flows to equalize pressure on both sides of the hatch. Moving the handle past this point requires disengaging a latch. Also mounted in the hatch are two check valves which open if the pressure in the airlock exceeds that in the workshop by 0.2 psi. At launch, this hatch was closed to separate the workshop from the rest of the habitable volume for pressurization. The workshop was vented during launch and then pressurized to 5 psia over a period of about 4 hours. During this time, the pressure in the rest of the habitable volume should

have remained at a low value. Instead, it increased, staying about 0.2 to 0.3 psi less than the pressure in the workshop until the flow of gas into the workshop had ended. After this, pressures equalized on both sides of the hatch. Apparently, gas was leaking either around the hatch or through one or both check valves. The check valves had opened as expected during venting and they may not have reseated properly. The first crew inspected the seal, and, although nothing unusual was found, the crew rigged flapper valves to fit over the check valves on the workshop side. Either the valves were effective, or a jiggling of the check valves when the hatch was first opened allowed them to seat properly, as there was no subsequent evidence of leakage. This hatch was used successfully nine times to seal off the lock section during extravehicular activity.

**Brackets.**- Structural support brackets for mounting equipment are located both inside and outside the Saturn Workshop. The secondary structures were designed with high factors of safety so that ground testing would not be necessary. No failures were reported.

**Meteoroid Shields.**- Protection against penetration by micrometeoroids is provided for part of the pressure shell of the docking adapter by aluminum panels 0.05 inch thick on the cone and 0.02 inch thick on a portion of the barrel. Fiberglass standoffs support the panels 3 inches from the pressure shell. Approximately 75 percent of the cylindrical portion of the docking adapter is protected by a radiator constructed of 0.03-inch magnesium, with attached cooling tubes, that is bolted to fiberglass standoffs. The radiator also protects the structural transition section of the airlock against penetration. The fixed airlock shroud and instrument unit, augmented by curtains made of fiberglass impregnated with rubber, protect the rest of the airlock and the forward dome of the workshop.

A wraparound shield of aluminum panels, 0.025 inch thick, was to have protected the cylindrical part of the workshop against penetration by micrometeoroids. This shield was held tightly against the cylindrical shell of the workshop at launch and was to have been deployed 5 inches from the shell when the Saturn Workshop reached orbit. The shield was lost during ascent (4.3.1). As shown in table 4-I, there was a resulting reduction in the probability that impact by a micrometeoroid would not cause loss of internal pressure. This was accepted, and the mission proceeded. During the 9 months of the mission, no loss of atmosphere occurred because of penetration.

Table 4-I.- Probability of No Penetration by Micrometeoroids

	28 days	56 days	240 days
With shield	0.999+	0.999	0.995
Without shield	0.995	0.990	0.958

mand module. With the exception of some capture and latching problems described in reference 15, 16, and 17, the docking ports were satisfactory.

**Docking Ports.**- The docking adapter has an axial and a radial docking port, both identical in construction. They have standard Apollo drogues and docking interfaces. The axial port is equipped to transfer electrical power, communications, and conditioned air to the com-

## 4.2 MECHANISMS

### 4.2.1 Deployment

The Saturn Workshop could not be launched in its orbital configuration because of aerodynamic and structural loads, and a sequence of deployment is necessary after it reaches orbit. Each step in the sequence is irreversible. Command

signals originating in the instrument unit initiate the sequence, although deployment can be commanded from the ground. Pyrotechnic devices, stored high-pressure gas, electrically driven devices, and mechanical devices such as springs are used to supply the force necessary to effect the deployments. Some of the deployed elements are shown in figure 4-6.

- |                             |                                   |
|-----------------------------|-----------------------------------|
| A. Disccone antennas        | E. Solar observatory solar array  |
| B. Workshop solar array     | F. Rendezvous and ranging antenna |
| C. Solar array beam fairing | G. Solar observatory              |
| D. Parasol thermal shield   | H. Deployment truss               |



Figure 4-6.- Saturn Workshop with all elements deployed.

Radiator Shield.- The location of the refrigeration radiator at the aft end of the workshop places it in the region affected by exhaust gas from the rocket motors used to separate the launch vehicle. A shield protects the radiator surface from impingement by the exhaust gas. Two concentric pieces connect the shield to the radiator. The inner piece is attached to the center of the

radiator, the outer piece is attached to the shield, and the two pieces are locked together by retaining balls (fig. 4-7). A plunger holds the retaining balls in place. High-pressure gas is admitted to an actuator which drives the plunger to a point at which the retaining balls are free to move, allowing the pieces to separate. A spring compressed between them expands, ejecting the shield with enough velocity to preclude further contact with the Saturn Workshop. Jettisoning the radiator shield was initiated 10 minutes after launch. The operation was successful.

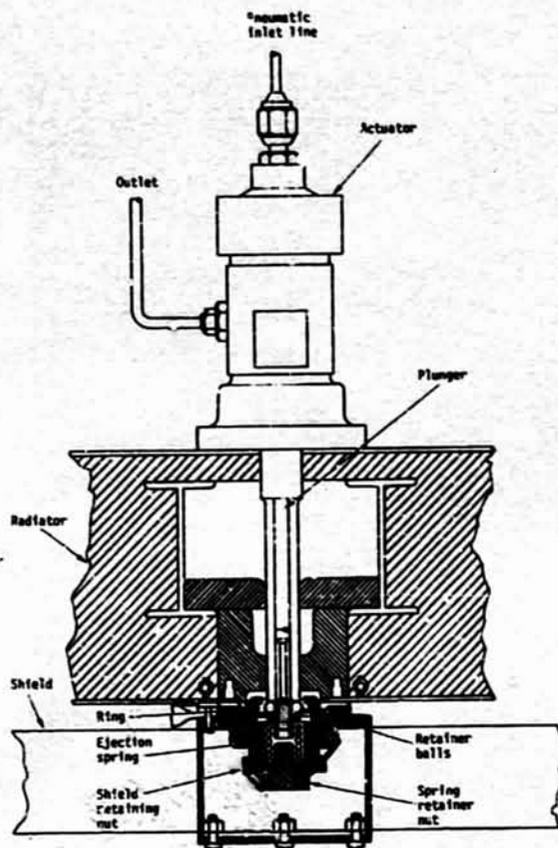


Figure 4-7.- Radiator shield release.

the Saturn Workshop. Jettisoning the shroud was successfully completed 15 minutes after launch.

**Discone Antenna Booms.**- These two booms are protected by the shroud until the Saturn Workshop reaches orbit. Each boom consists of an inner and outer section. At launch, the outer section is folded back against the inner section, and both sections together are folded back against the supporting truss, where straps secure them. To deploy the booms, an electrical current heats and breaks a wire, releasing a plunger which allows a scissors assembly to open. This releases a cable restraining

**Shroud.**- At launch, a shroud composed of conical and cylindrical segments encloses the docking adapter, solar observatory, and airlock (fig. 2-1) to provide an appropriate aerodynamic shape. The shroud consists of four longitudinal sections fastened together with box members and rivets. An expansible bellows containing a detonating fuse is compressed between the box members. Ring frames at the aft end and at the juncture between the cylindrical and conical segments are connected across the joints by tension links held by pins. Each pin is part of an actuating mechanism comprising a cylinder, the pin itself, and a piston to which the pin is attached. To release the tension link, gas from a pressure cartridge forces the piston to move, pulling the pin free of the tension link. Igniting the detonating fuse within the expansible bellows causes the bellows to expand with enough force to shear the rivets and to propel the four sections of the shroud away from the Saturn Workshop (fig. 4-8). Ten minutes after launch, a maneuver pointed the Saturn Workshop longitudinal axis toward the center of the Earth with the forward end down, to maximize the separation distance between the sections of the shroud and

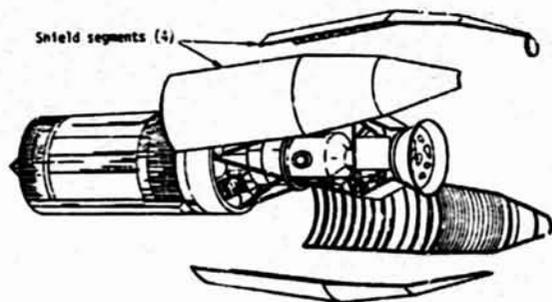


Figure 4-8.- Jettisoning the shroud.

the sections of the booms, and torsion springs in the rotary joints then force the booms to unfold. Viscous dampers in the rotary joints provide smooth rotation, and mechanical locks in the joints engage when the booms are fully extended to hold them in place. Deployment of the booms was initiated at 17 minutes after launch and completed without trouble.

Solar Observatory.- For launch, the solar observatory, with its solar arrays folded, is folded into the X axis of the Saturn Workshop and is enclosed by the shroud. Split fittings, attached to the shroud at the planes of separation, provide a floating support until after the shroud is jettisoned. When the longitudinal sections of the shroud separate, the split fittings pull apart and four rigidifying mechanisms lock the solar observatory to the upper part of the supporting truss. This two-part truss is connected together by a pair of trunnions having a common axis, and the lower part is attached to the fixed airlock shroud. The first command initiates deployment of the solar observatory by firing pressure cartridges to retract pins so that the upper part of the supporting truss is free to rotate. The next command starts electric motors to wind in two cables connecting the upper and lower parts of the supporting truss, to rotate the solar observatory 90 degrees (fig. 4-9). The cables are attached to a reel on each part. The electric motors drive the reels in opposite directions, winding in the cables and pulling the parts together. When the parts meet, a hook attached to the upper part engages a member on the lower part, firmly latching both parts together in the deployed position. The next command releases four axial launch locks holding the canister rigidly in place, completing the deployment of the solar observatory. Deployment was initiated 17 minutes after launch and successfully completed 8 minutes later.

Solar Observatory Array.- Each of the four solar array wings consists of rectangular panels hinged together and to the rack. Struts pinned to the centers of the edge members of the panels are pivoted together at their ends to form a scissors assembly. The struts nearest the rack are connected to a crossbeam attached to two sliders. Gas from a pressure cartridge rotates a torque tube, releasing a rod which holds the array at launch. Cables attached to the top and bottom of the sliders and driven by electric motors then move the crossbeam. Deployment of the array was successfully completed 28 minutes after launch.

Workshop Array.- There are two solar array wings mounted on opposite sides of the workshop. Each wing consists of solar panels hinged together into three sets, or wing sections, and folded at launch into a cavity on the underside of a supporting beam, which itself is folded along the side of the workshop over the meteoroid shield. This beam protects the arrays from aerodynamic forces during ascent and provides structural support before and after they are deployed. Each beam is held flush against the structural shell of the workshop during launch by attachments at four points on the aft skirt and at two points on the forward skirt. The beam is bolted to a track secured by tension links consisting of two pieces which fit together around two explosive expansible tube assemblies. The track permits relative motion between the beam and the workshop. A charge is fired to break the tension links on the inboard side; should this fail to release the beams, a second charge is fired to break the links on the outboard side.

After being released, the beams are free to rotate about hinges located in the forward fairing. An actuator consisting of a helical spring wrapped around a cylinder containing a piston and hydraulic fluid presses against a lever arm attached to the beam. Freeing the beam allows the spring, which is compressed during installation, to expand, pushing the beam outward. The piston forces

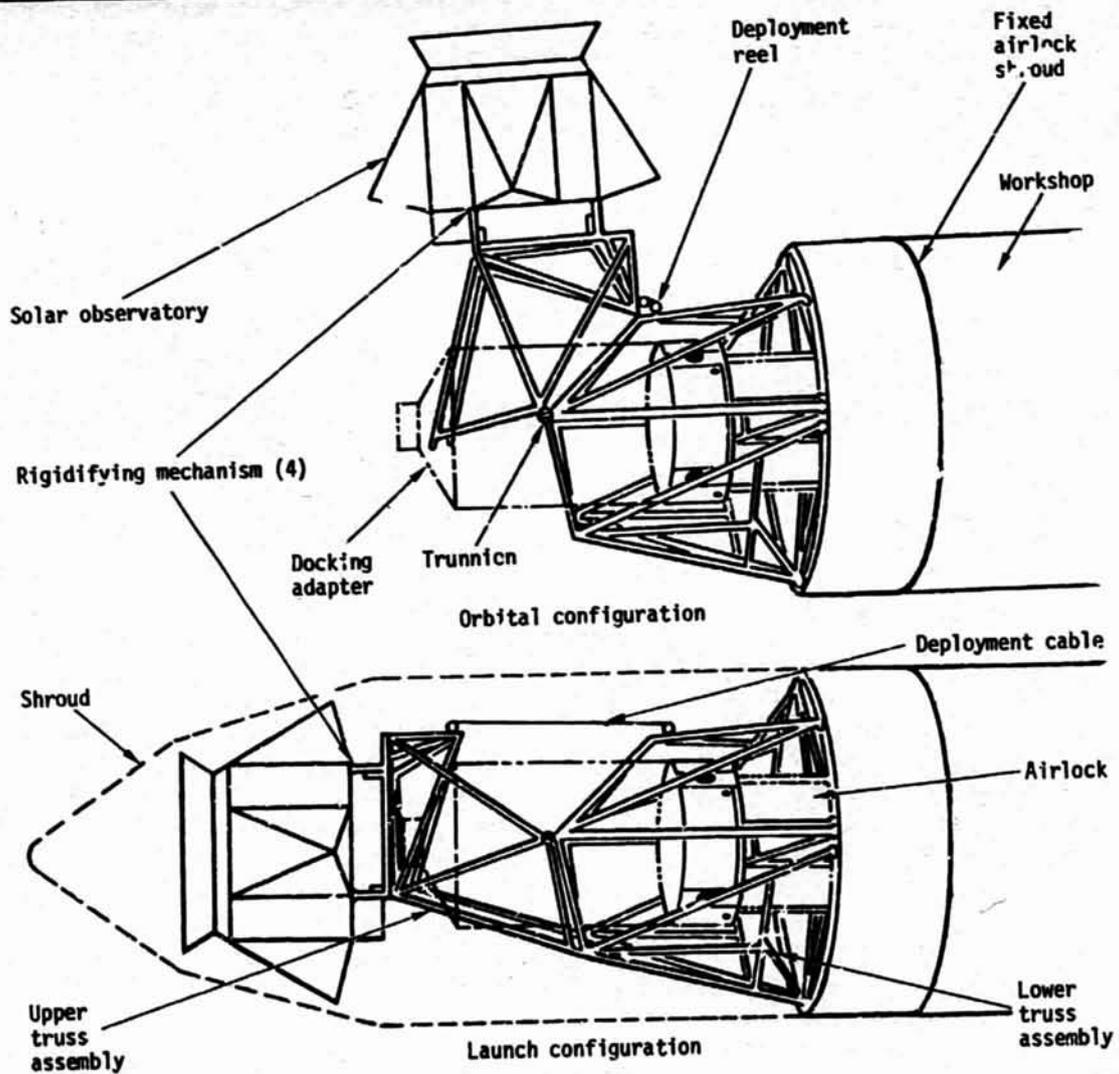
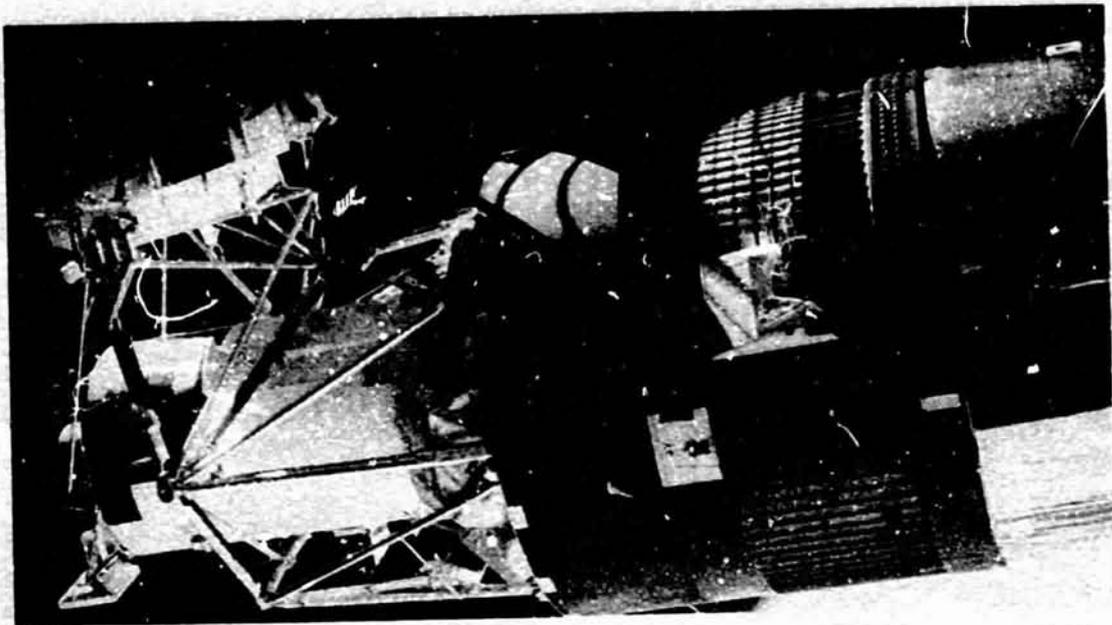


Figure 4-9.- Solar observatory deployment.

hydraulic fluid through an orifice to damp the motion. When the hinge reaches its limit, a latch is tripped, locking the beam in place.

Deployment of the solar array wing sections follows that of the beams. The three wing sections carried by each beam are mechanically independent. Hinges between the solar panels permit the wing section to be folded, accordion-fashion, for storage. Each wing section has two hinged stabilizing beams which assist in deployment and give rigidity to the deployed wing section. Restraining mechanisms mounted inside the cavity of the beam support each wing section and its stabilizing beams before deployment. Each restraining mechanism has two cinch bars. One cinch bar is connected to the beam by a pivot and is held in place by a tension strap. Breaking the tension strap with an explosive charge releases this cinch bar, which swings out of the way, releasing the solar panels on one side. At the same time, the motion of this bar, translated through a shaft, releases the other cinch bar, completing the release of the panels. Springs in the hinges between sections of the stabilizing beams cause these beams to extend, carrying the solar panels with them. The two stabilizing beams attached to each wing section are linked to a common damping mechanism which synchronizes and regulates the deployment.

A signal received approximately 63 seconds after launch indicated the release of solar array wing 2. Approximately 593 seconds after launch, almost concurrently with ignition of the rocket motors for separation from the second stage, there was a loss of data from all transducers on this wing. Following its programmed sequence, the instrument unit commanded release of both beams 41 minutes after launch, and the solar arrays were commanded to deploy 11 minutes later. A subsequent signal indicated that the beam holding wing 1 had released, but there was no indication that the wing sections had deployed. The backup commands to release the beams and deploy the wings were given. Since no power was produced, it was assumed that deployment was incomplete. The first crew verified on Day 12 that solar wing 2 was missing (4.3.2) and wing 1 was partially deployed, held in position by a strip of the meteoroid shield (fig. 3-10). A crewman succeeded in removing the strip of meteoroid shield on Day 25 during an extravehicular activity (10.4), freeing the beam to rotate out. After 25 days in orbit, however, the hydraulic fluid in the actuator had become so cold that the spring could not move. This problem had been anticipated, and the crewman broke the clevis holding the actuator to the workshop by torquing the beam. The beam had enough momentum when it broke free to rotate to the fully deployed position.

The three wing sections in the beam had partially deployed when the cinch bars were released on Day 1. By the time the beam was deployed, the hydraulic fluid in the damping mechanisms on the wing sections was also too cold to permit the wing sections to deploy. A maneuver was made to expose them to direct sunlight, and the wing sections began to extend slowly. They were completely deployed and fully operational 6 hours later. Results indicate that deployment of both the workshop's solar array wings would have been normal if the meteoroid shield had not failed.

Meteoroid Shield.- During launch the shield was tight against the workshop pressure skin. On command, a confined detonating fuse inside an oval expandible tube would fire and force the tube to a round configuration, rupturing six tension straps. This would allow 16 preloaded torsion bars, 8 on each of the forward and aft workshop skirts, to rotate about 165 degrees to deploy the shield to a position 5 inches from the workshop skin. A folded panel section under the ordnance would unfold to provide the additional circumference. Latches

at four of the torsion bars would hold it in the deployed position. Approximately 63 seconds after launch, indications were received that the meteoroid shield had deployed. Subsequent data and analyses confirmed this, and the crew verified it during the flyaround on Day 12. This anomaly is described in 4.3.1.

#### 4.2.2 Doors

**Film Retrieval.**- The film-retrieval doors for the solar observatory experiments are operated manually and incorporate launch locks, mechanical latches, magnetic latches, and rim seals. The doors in the side of the canister have latches with spring-loaded lock pins to hold the latch pins in the retracted position. The door is opened by pushing the handle into a dust boot and pulling it to overcome magnetic latches. Friction between a spring and a curved rod keeps the door open. For each of the two doors in the Sun end of the canister the latch mechanism is unlocked by depressing a lock-release button on top of the handle and rotating the handle. The door is latched by rotating the handle in the opposite direction. The film-retrieval doors in the side of the canister operated as designed. The crew reported on Day 37 that one door would not lock mechanically but was being held closed by the magnetic latches. The second crew reported, however, that this door was mechanically locked and operated normally. Each door in the side of the canister was used a total of six times. One of the film-retrieval doors in the Sun end of the canister was opened and closed seven times without incident. The other door was opened and closed five times. On two occasions, this door was difficult to open, but this did not prevent operation.

**Aperture.**- Each solar observatory experiment instrument in the canister is equipped with an aperture door for thermal and contamination control (fig. 4-10).



Figure 4-10.- Doors on Sun end of canister.

The doors are identical except in size and shape. Each is a fiberglass shell containing multilayer insulation, with a shaft at one corner for opening and closing. Opposite the shaft, a tapered latch, fitting into a U-shaped, ramp-latch stop attached to the sunshield, holds the door closed during ascent. A bulb-shaped seal of silicone rubber covered with low-friction cloth, attached to the perimeter of the door's face, seals the aperture at the ramp. An identical mechanism (fig. 4-11) comprising two electric motors, a threaded spindle, a carriage, a lever, and limit switches opens and closes each door. The two motors, either singly or together, rotate the spindle to move the carriage and the lever and shaft. The limit switches stop the motors when the door is fully open or closed. The doors and mechanisms were designed for 5000 opening and closing cycles, but only 3 of the 10 doors continued to operate normally for the duration of the mission (4.3.3). The ultraviolet spec-

trograph door was cycled 500 times, the hydrogen alpha 1 door 800 times, and the fine Sun sensor door 3600 times.

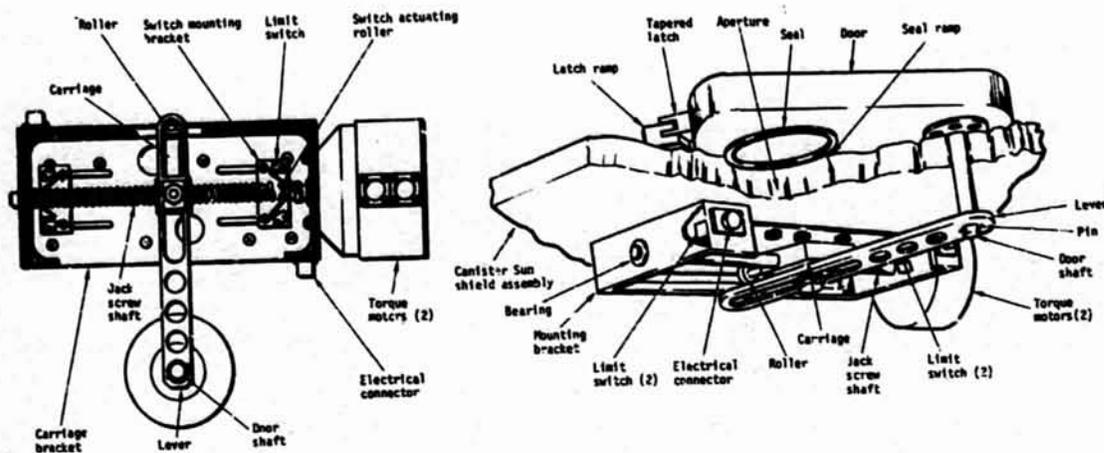


Figure 4-11.- Typical aperture door mechanism.

### 4.3 ANOMALIES

#### 4.3.1 Workshop Meteoroid Shield

Approximately 63 seconds after liftoff, and as the launch vehicle passed through Mach 1 and was approaching the maximum dynamic pressure, the meteoroid shield that surrounded the cylindrical section of the workshop was torn away. The many serious problems that resulted and the actions taken to correct them are described in 3.2. Of the several possible failure modes identified, the most probable was from aerodynamic loads that resulted in internal pressures in the auxiliary tunnel in excess of the design loading. This pressure forced the forward end of the thin shield out from the workshop and into the supersonic airstream, where the shield was stripped away. Some of the information from references 13 and 31 leading to this conclusion is presented here. It is based on available data from instrumentation that had been installed for deployment purposes and on measurements of vibrations and electrical power. The number, location, and sampling rates of these were not adequate for a complete sequential history of the events, and a certain amount of hypothesizing is required.

The meteoroid shield was a very lightly built cylindrical structure 270 inches in diameter (in the deployed condition) by 265 inches long, weighing about 1200 pounds. The general layout is illustrated in figure 4-12. The workshop, which it surrounded, is deleted in this figure for clarity. The shield was formed of 16 curved sheets of 2014 T6 aluminum panels, 0.025 inch thick, assembled to form the cylinder shown. The forward and aft ends were reinforced with curved 7075 T6 angles. Various features were included in the assembly to hold it in place, deploy it in orbit, and provide access to the workshop interior during prelaunch activities. The principal means of holding the shield in place in orbit, and to a lesser extent during powered flight, was a set of tension straps under the main tunnel. These straps were bonded to the workshop wall and fitted with a hinge on each end to mate with the butterfly hinge that attached to the adjacent shield panel. The butterfly hinges were designed to rotate on deployment so as to lie against the sides of the main tunnel, which enclosed the tension straps and some cable runs.

Proceeding clockwise from the tension straps and butterfly hinges in figure 4-12, the next special feature is the auxiliary tunnel. This tunnel extended in an arch between panels of the thin meteoroid shield. The 28 arch-shaped titanium

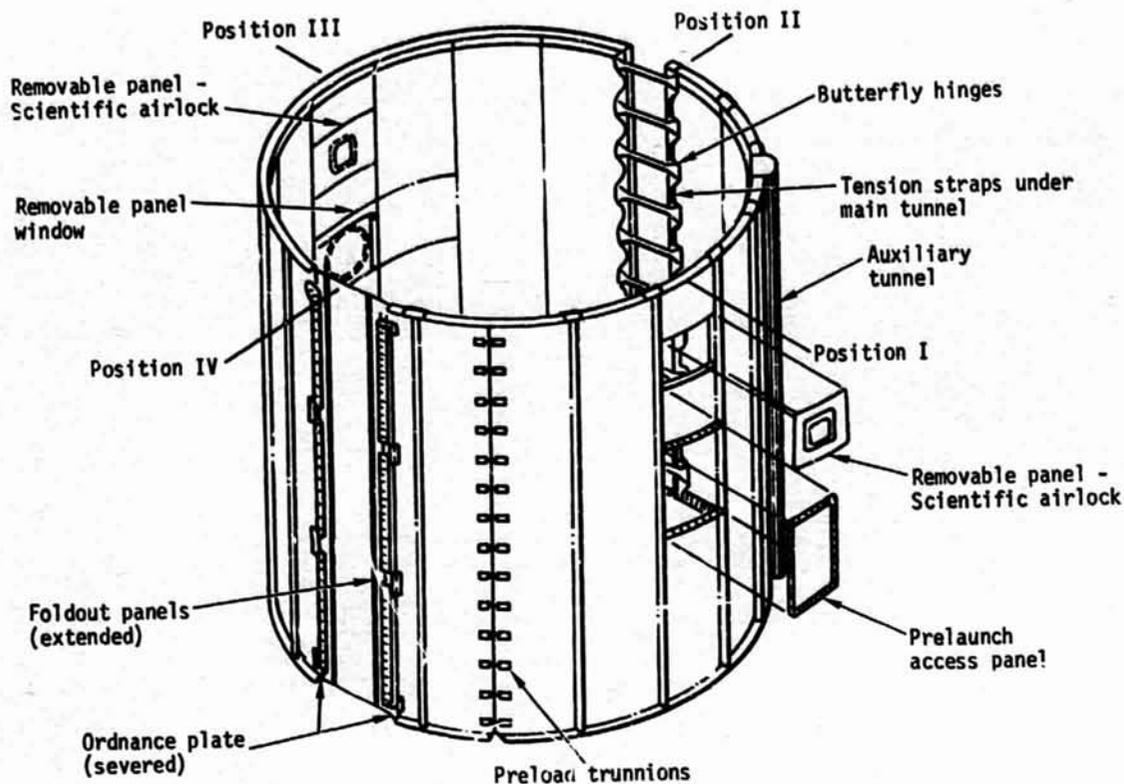


Figure 4-12.- Meteoroid shield.

frames of the tunnel provided a very springy section in the relatively rigid hoop of the rest of the shield. These frames were a structural tie between two shield panels and provided both regulation of the preloading of the shield and a relief for diametrical workshop changes caused by thermal and pressure variations. The auxiliary tunnel also enclosed a smaller tunnel covering the wiring for the thruster attitude control system. Farther around, in position I, there were two curved rectangular smaller panels included to provide prelaunch access to the workshop.

Between positions I and IV, the two halves of the shield overlapped and were joined by a series of 14 trunnion bolts and straps. These trunnion bolts were used to adjust the tension with which the shield was held against the workshop during launch. To provide the extra 30 inches of perimeter required when the shield was deployed, a foldout panel assembly, released by ordnance, was included in the shield adjacent to the trunnions. There were small panels located over the scientific airlock and wardroom window at position III, and the shield was completed at the butterfly hinges and tension straps at position II. The two solar array wings, which are not shown in the figure, were folded along the workshop outside the meteoroid shield. They extended forward and aft of the shield, with the hinges at the forward end. They were secured to the workshop at both ends for launch.

To provide a uniform tension throughout the shield upon assembly and rigging for flight, and to permit transfer of the trunnion bolt tension into the frames of the auxiliary tunnel, it was necessary to minimize friction between the shield and the external surface of the workshop. This was accomplished by applying Teflon coating to the entire inner surface of the shield assembly. Special care was also

taken to ensure that all fastening rivets be either flush with or below the Teflon surface of the shield. In preparation for launching, the shield was tightened against the workshop in an effort to get contact over the entire surface.

The launch position of the shield is shown in figure 4-13 and the shield deployment mechanism is described in 4.2.1. It can be seen from figure 4-13 that when the ordnance fired at position IV and released the shield, the torsion links on one side rotated in a direction opposite to those on the other side. The torsion rods and the butterfly hinges on each side of the main tunnel caused the radial displacement of the shield. The meteoroid shield should therefore be regarded as a very limp system which depended on being stretched tight around the workshop to withstand the aerodynamic, vibration, flutter, and thrust loads during boost flight. After deployment, it needed very little strength to serve its primary function as a meteoroid shield.

The first anomalous indication was an increase in the second stage telemetry reflected power, from a steady 1.5 watts, beginning at 59.80 seconds after launch. By 61.04 seconds, the reflected power had reached about 1.75 watts, and by 80.38 seconds, it had stabilized at about 2 watts. This abnormal increase in power might be indicative of a vehicle physical configuration change which altered the antenna ground plane characteristic. At 60.12 seconds, the shield torsion rod 7 forward (measurement G7036) indicated a slight change toward the deployed condition. The location of this and other instrumentation associated with the meteoroid shield is shown in figure 4-14. At 61.78 seconds, the vehicle roll rate decreased slightly from the normal value of 1.1 deg/sec clockwise looking forward. Figure 4-15 is a graph of the roll rate versus range time during the time of interest. The next torsion rod 7 forward sample, at 62.52 seconds, revealed a further relaxation. The increase in telemetry reflected power and the movement of torsion rod 7 forward tend to indicate lifting of the meteoroid shield between positions I and II.

A sensor on the workshop film vault showed an abnormal vibration at 62.75 seconds, which was followed by disturbances throughout the vehicle sensed by other accelerometers. At 62.78 seconds, the roll rate gyro sensed a sudden clockwise roll rate resulting in a peak amplitude of 3.0 deg/sec clockwise at 62.94 seconds. A sensor in the instrument unit showed a maximum peak-to-peak shock of 17.2 g's at 63.17 seconds. During the time the vehicle was sensing these disturbances, several slower-rate shield and array wing measurements showed drastic changes. Because these measurements were sampled only once every 0.1, 0.8, or 2.4 seconds, it is uncertain when the physical condition actually changed. Figure 4-16 is a graphic representation of some of the applicable measurements associated with the 63-second anomaly. For the shield and array wing data, the last normal and first abnormal times are shown. Where no last "normal" sample is shown, the sampling is continuous or has no significant bearing on the identification of the failure mode.

At 62.78 seconds, C7011, a temperature measurement, was lost. This measurement failure could have been caused by damage to the sensor or its cabling, shown in figure 4-16 by dashed lines. This was most likely a result of shield failure in the area between positions I and II. The measurements K7211, C7013, K7010, K7011, and K7012 can be considered normal at that time because they were normal during the previous sample and were sampled later than 62.78 seconds and still found to be normal. Since array-wing-secured indications and ordnance tension-strap indications were known to be good then, the evidence leads to two

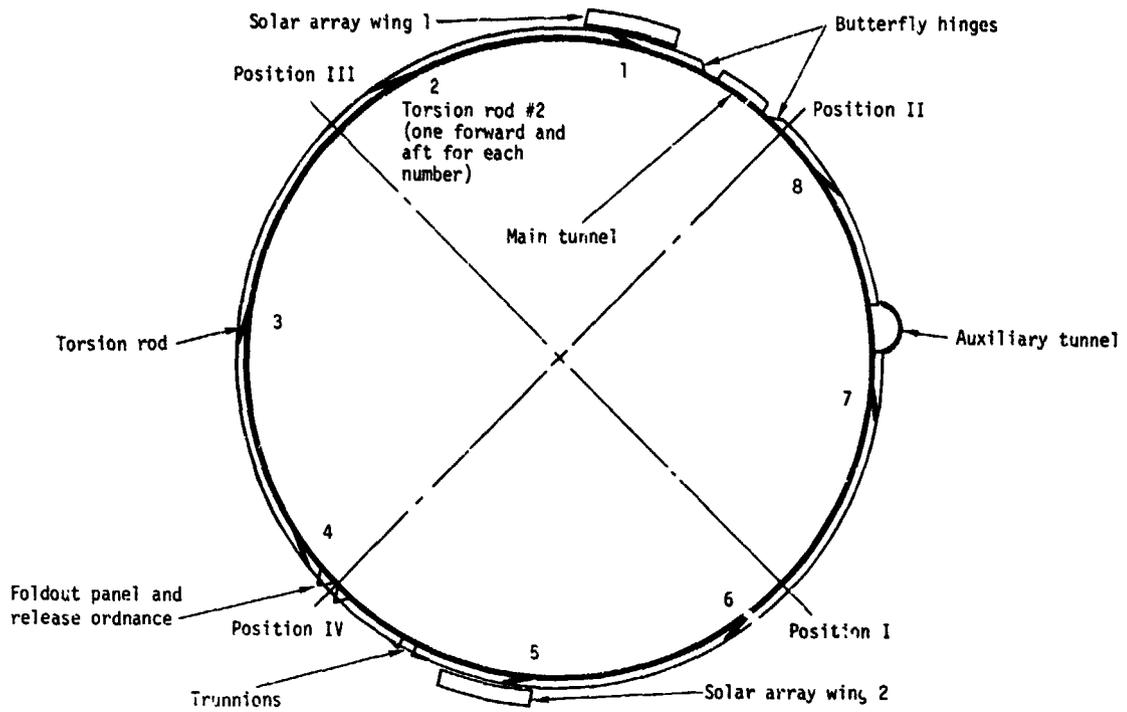


Figure 4-13.- Meteoroid shield in launch position.

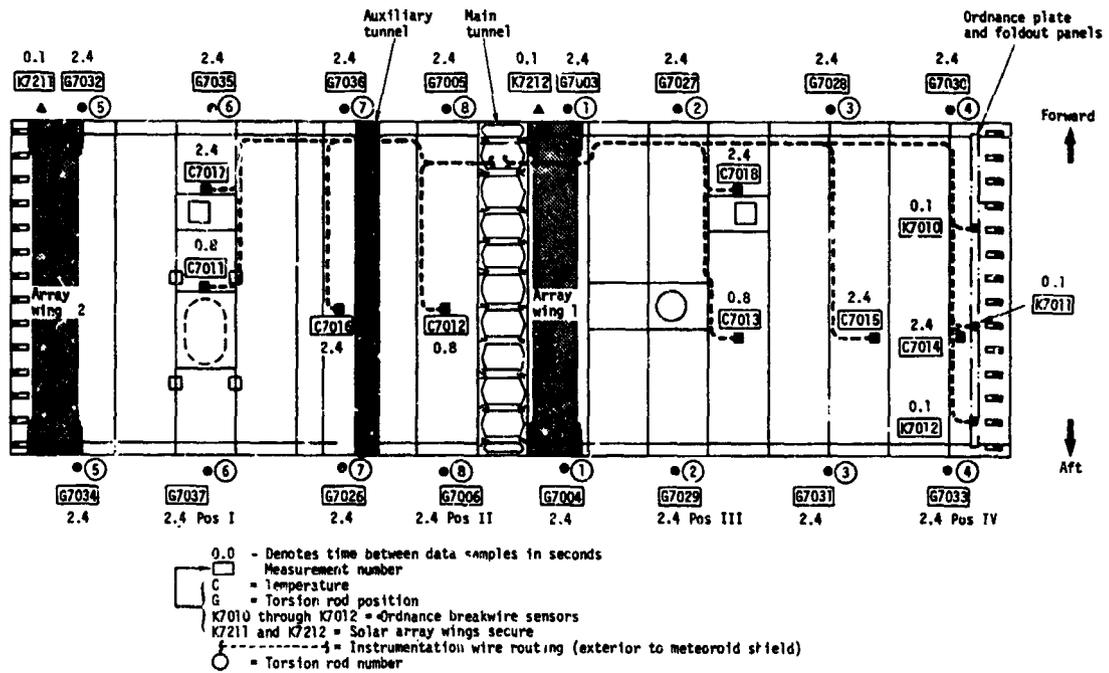


Figure 4-14.- Meteoroid shield and instrumentation layout.

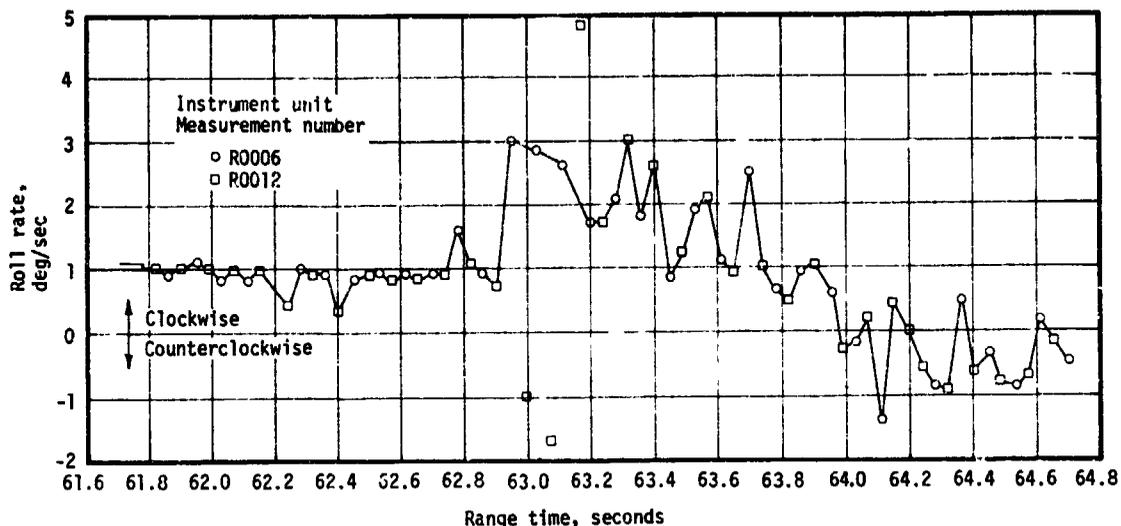


Figure 4-15.- Roll rate versus range time.

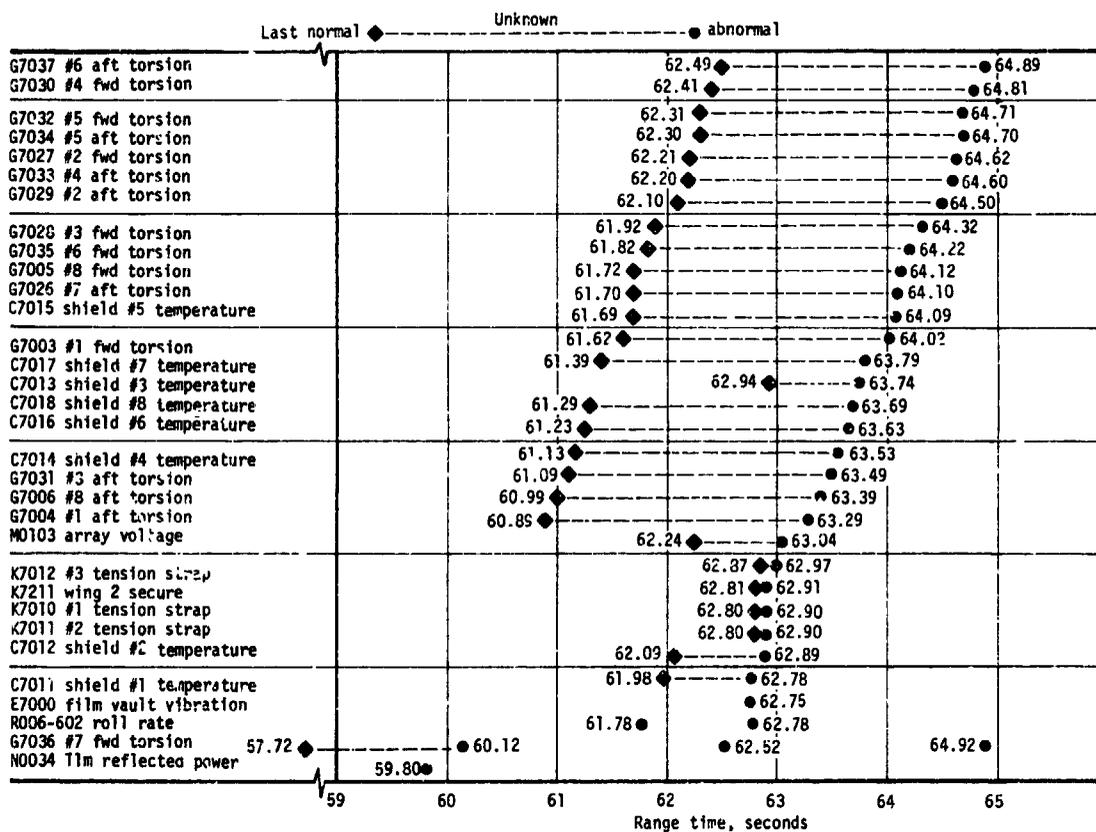


Figure 4-16.- Time sequence of 63-second anomaly instrumentation.

conclusions at this point: the meteoroid shield failure began before array wing 2 became unlatched, and the ordnance did not fire prematurely.

The tension strap measurements K7010 and K7011 were normal at 62.80 seconds, and K7012 was normal at 62.87 seconds. However, by 62.91 seconds, measurements C7012, K7010, K7011, and K7211 had failed, while K7212 (wing 1 secured) and C7013 were known to be normal by a later sample. The abnormal telemetry indications C7012, K7010, and K7011, like C7011, could have been caused by sensor or wiring damage. Measurements K7010, K7011, and K7012 were, in fact, only breakwires placed across the ordnance tension strap. The failure of measurement K7211, however, reveals that the array wing 2 was no longer secured to the workshop. This is an indication that the wing had moved out at least between 4.7 and 20.2 inches as measured at the aft end of the wing perpendicular to the workshop.

At 62.97 seconds, measurement K7012 (tension strap) was detected as failed. Slightly later, at 63.04 seconds, the first indication of increased array wing voltage appeared, when measurement M0103 showed a slight increase. This is attributed to sunlight illuminating exposed sections of the partially deployed (unlatched) wing 2. Other array voltages fluctuated throughout the remainder of the launch phase for the same reason. Between 62.97 and 64.89 seconds, all of the measurements related to the shield became abnormal, but the wing-1-secured measurement (K7212) was still normal.

The data indicate that the most probable sequence of meteoroid shield failure was initial structural failure between array wing 2 and the main tunnel (between positions I and II). It appears likely that the initial failure propagation was from this area, since the wardroom window thermocouple indication (C7013) remained normal at 62.94 seconds, after the K7010 and K7011 tension strap measurements had failed at 62.90 seconds, and after wing 2 was indicated unlatched at 62.91 seconds.

The auxiliary tunnel, shown in figure 4-17, extended the full length of the shield. The design intent was that the aft end of the tunnel be sealed for "no leakage" and that the forward end be vented into the base region of the forward fairing so as to discharge air into the forward low-pressure region. This was intended to provide a crushing pressure (an external pressure exceeding the internal pressure) over the entire tunnel. Venting was provided through an outlet of 10 in.<sup>2</sup> under the corrugations of the tunnel cover at the aft end of the forward fairing. The tunnel was intended to be sealed at the aft end by a rubber boot assembly, shown in figure 4-18 in both the stowed and deployed positions. The figure shows that the tunnel was displaced some 5 or 6 inches circumferentially upon deployment of the shield. Postflight investigation revealed, however, that the aft end of the tunnel was not completely sealed in three places (fig. 4-19) because of:

a. The unexplained omission of a seal or cap on two hollow structural stringers on the aft skirt which extended into the aft fairing of the auxiliary tunnel, resulting in a leakage area of about 2.2 in.<sup>2</sup>.

b. An inadequate metal-to-metal fit between the aft fairing of the auxiliary tunnel and two circumferential stiffeners, resulting in approximately 2 in.<sup>2</sup> of additional leakage area.

c. An unplanned venting resulting from leakage past a molded rubber boot used to seal the movable joint at the rearward facing end of the auxiliary tunnel. A metal yoke provided a positive clamp to a molded flange on the bottom of the

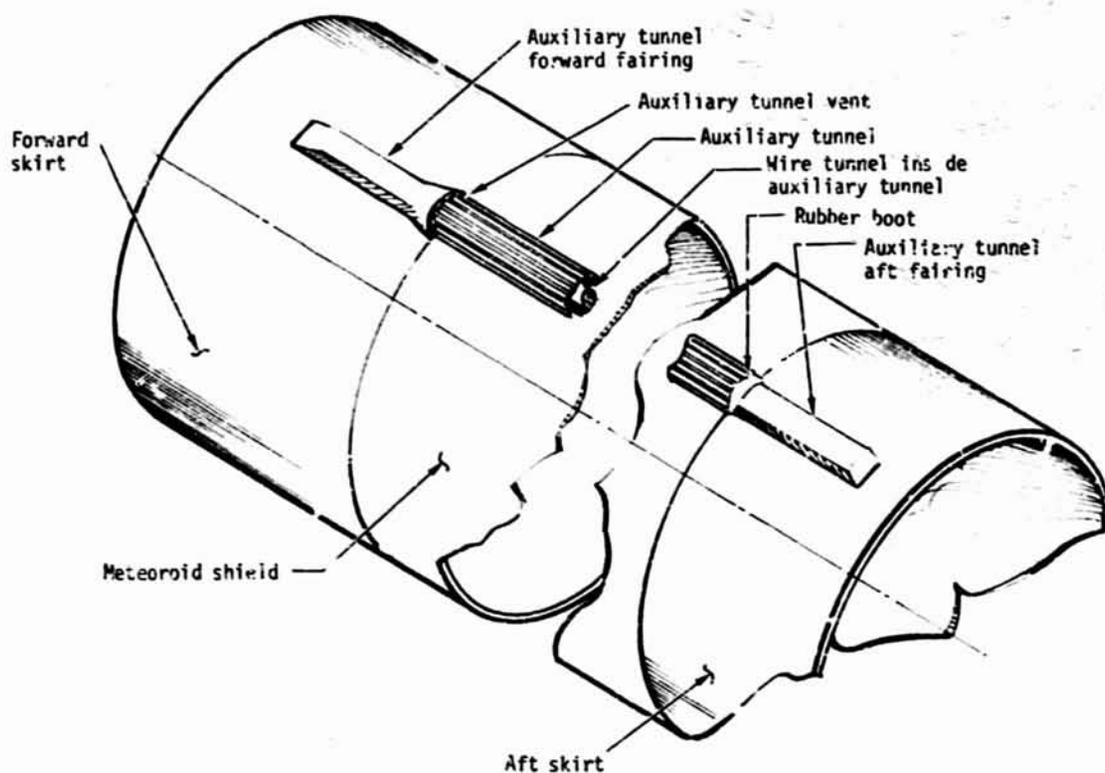
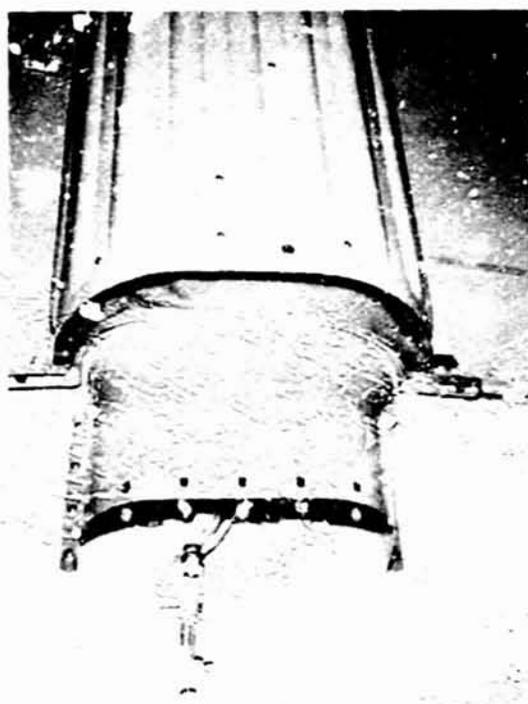


Figure 4-17.- Auxiliary tunnel.



(a) Stowed position



(b) Deployed position

Figure 4-18.- Auxiliary tunnel boot, looking forward.



Closeups of boot and aft fairing leak points.

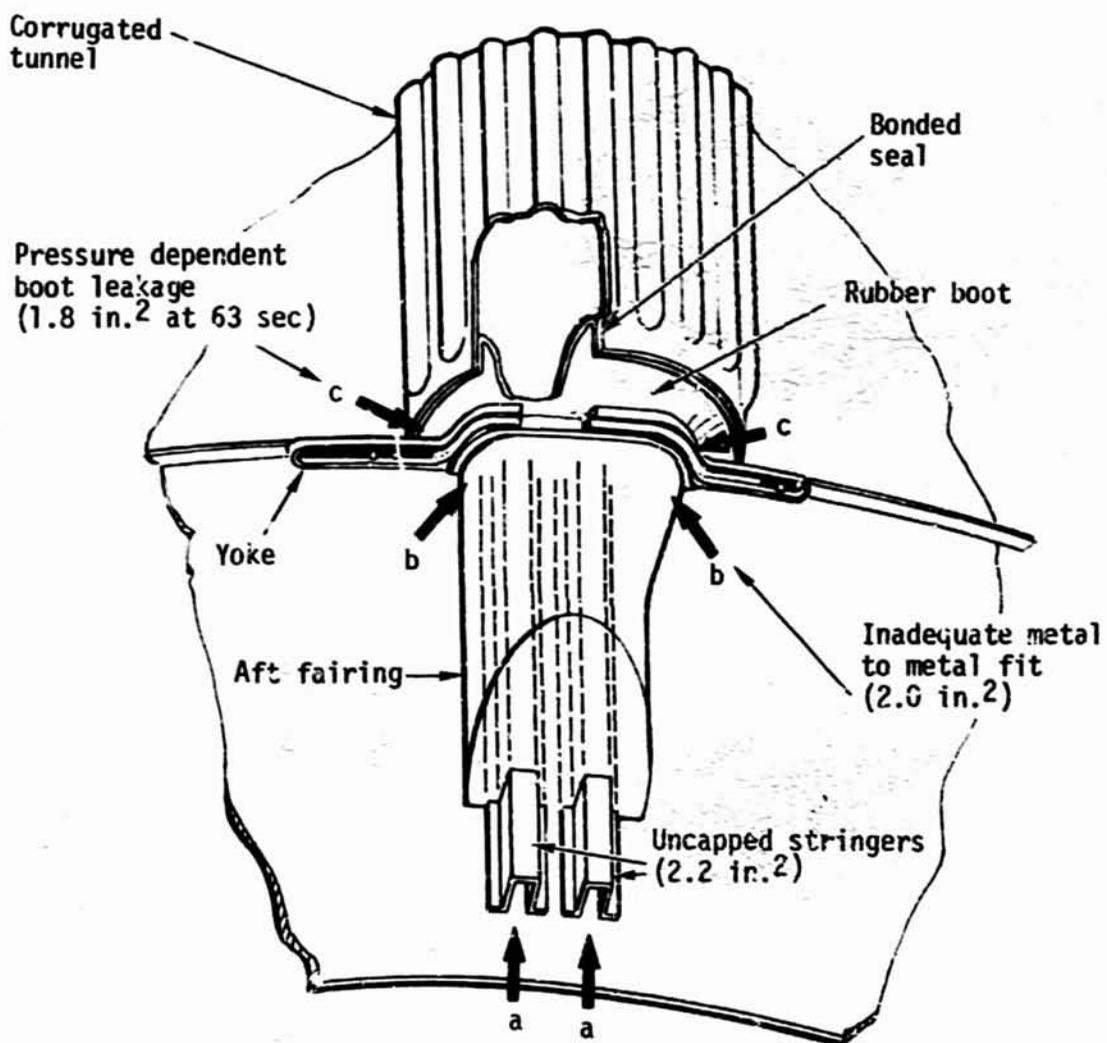


Figure 4-19.- Auxiliary tunnel leaks (aft end).

boot over the rigid aft fairing. A bonded seal was achieved between the upper molded flange on the boot and the auxiliary tunnel. Because the auxiliary tunnel was required to lift freely away from the workshop and move circumferentially upon deployment in orbit into the position shown in figure 4-18, only a wiping butt seal could be achieved along the bottom edges of this boot "seal." When a differential pressure was applied to the boot, the butt seal deflected away from the workshop surface and created two orifices of semi-oval cross section whose size depended upon the applied pressure differential. A full-scale test was performed to determine the leakage rate at the bottom edge of the rubber boot, and this indicated that a pressure-dependent leakage area of 1.8 in.<sup>2</sup> would occur under the flight environment existing at 63 seconds.

The above three sources of unplanned leakage resulted in a higher pressure in the auxiliary tunnel and a pressure differential significantly different from the design. Postflight calculations indicated that, for the total 6 in.<sup>2</sup> of leakage area into the aft end of the tunnel, the pressure distribution along the tunnel at Mach 1 would give a bursting pressure over the forward part and a crushing pressure over the remainder as shown in figure 4-20. These deduced pressures produced large lifting forces on the forward part of the tunnel and adjacent shield areas. The effect would be to lift the forward end of the auxiliary tunnel and the adjacent shield until a critical position was reached where high velocity ram air would rush under the shield and tear it outward from its mountings on the workshop.

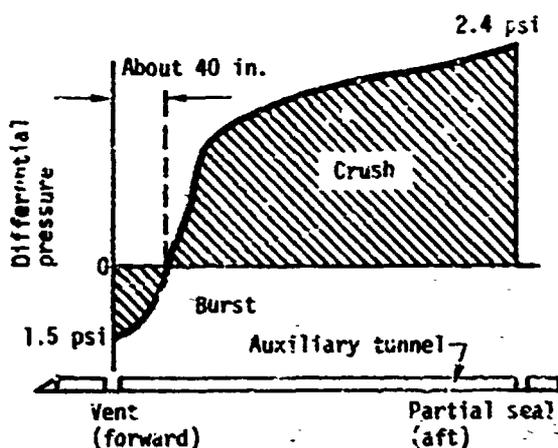


Figure 4-20.- Calculated auxiliary tunnel pressure differential.

Another means of producing bursting pressures under the forward edge of the shield in the region of the auxiliary tunnel could have been a wave pattern produced by the flared portion of the auxiliary tunnel forward fairing. At low supersonic flight speeds, the high and low pressure regions (the compression and expansion from the flare) extend to considerable distances away from the tunnel itself. High pressure over the meteoroid shield forward edge and lower pressures aft would tend to lift the overall structure. Lifting due to this mechanism would be indistinguishable from that due to auxiliary tunnel leakage described above.

Postflight analytical studies using a finite element model indicated that the deflection of the auxiliary tunnel and shield away from the workshop tends to become divergent. That is, as an area of the shield becomes exposed to a differential burst pressure, the shield lifts up, exposing additional area, which results in further lifting. Experimental studies were also made using an air bladder test rig to generate burst pressures over the forward edge of the auxiliary tunnel area and crush pressures over the rear. The conclusion of both of these efforts is that the meteoroid shield and auxiliary tunnel were quite limp and easily lifted from the workshop into the slipstream. A burst pressure of about 0.5 psi was found to be sufficient to effect this failure mode.

The postulated sequence of the most probable failure mode is shown in figure 4-21. The events are designated on the figure by times which are consistent with the available data, and are described below:

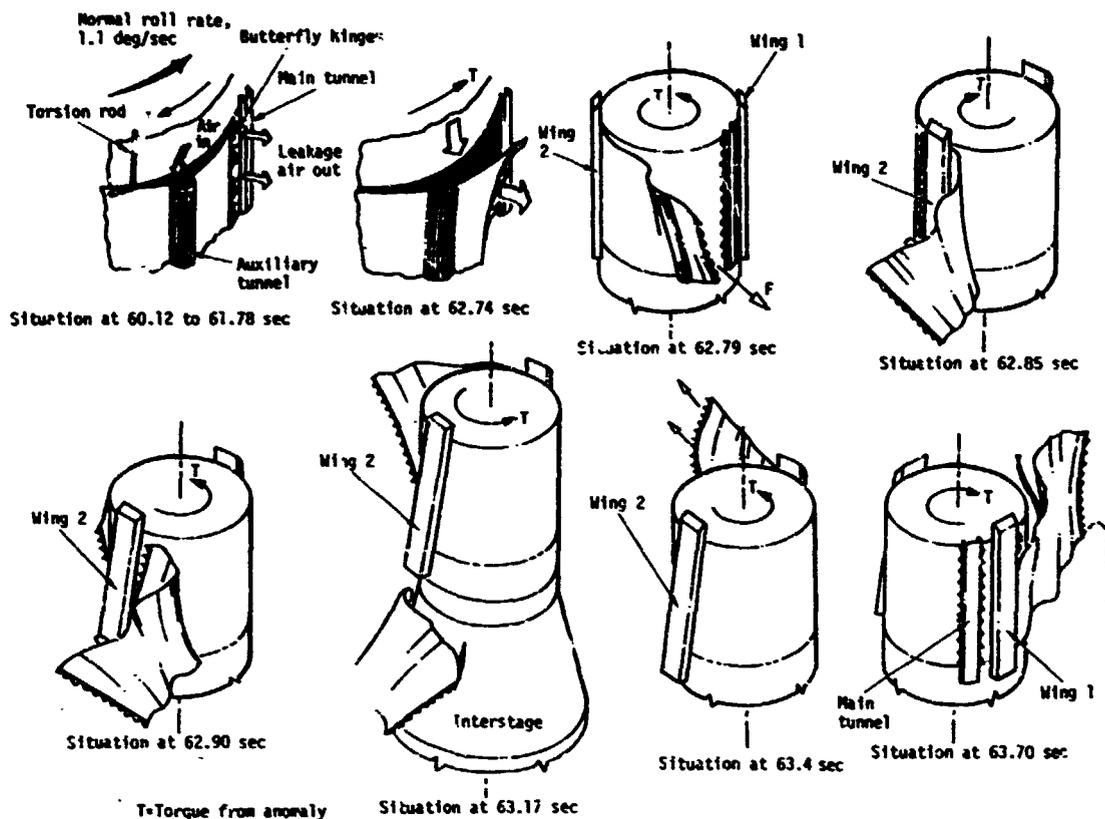


Figure 4-21.- Meteoroid shield dynamics.

60.12 seconds.- Meteoroid shield liftoff and local inflation in the vicinity of the auxiliary tunnel was indicated by a small shift in position of the torsion rod on the forward edge just to the left of the tunnel.

61.78 seconds.- Air entered the forward facing opening, raising the pressure under the shield, and high mass flows escaped through the adjacent holes in the butterfly hinge. This flow produced reactive forces causing a gradual decrease in roll rate between 61.78 seconds and 62.74 seconds.

62.74 to 62.79 seconds.- Burst pressure under the auxiliary tunnel and adjacent shield caused a large tangential load on the forward section of the butterfly hinge, causing the whole hinge to break. Flyaround inspection indicated that the failure of the butterfly hinge occurred at the hinge line adjacent to the main tunnel. Aerodynamic drag on the shield, including the bulky auxiliary tunnel, produced tension in the shield and pulled on the vehicle so as to roll it in the direction shown, that is, opposite to that noted earlier. The large area and mass of this metal "flag" induced a more rapid change in roll rate than earlier jetting through the butterfly hinge. This process terminated as the shield started to wrap around and lift wing 2.

62.79 to 62.90 seconds.- During this interval the shield was wrapping around array wing 2, producing a negative roll torque in the vehicle. At about 62.85 seconds the wing tiedowns were broken.

62.90 seconds.- Upon release of wing 2, the tension in the shield was transferred to the trunnions, causing failure of the trunnion straps. Upon separation of this section of the shield, the negative roll torque ended.

62.90 to 62.95 seconds.- In this interval, the remaining section of the shield began unwinding, introducing a large positive roll torque.

63.17 seconds.- A large shock was detected by the instrument unit upper mounting ring vibration sensor because of the impact of the separated section of the shield upon the conical interstage between the workshop and the launch vehicle.

63.70 seconds.- The shield continued to unwind and whip until 63.70 seconds, when it reached array wing 1. As the shield began to wrap around this wing, a negative roll torque resulted. The shield then ripped apart from top to bottom at the longitudinal joint adjacent to wing 1, pulling a portion of the joint assembly over the wing as the shield section departed. However, it did not pull the wing loose. From this point on, the vehicle showed normal response to its roll control system. Figure 3-10 is a photograph which shows a portion of the meteoroid shield that remained and how it was attached to array wing 1.

The loss of meteoroid protection did not affect the mission, but the resultant thermal problems and the subsequent loss of the workshop solar array wing 2 from the damage caused when the shield was torn off had major impacts on getting the mission started. These are described in sections 3, 7, 8, and 9. However, the successful repairs and changes in operational procedures that were made to counteract these losses enabled eventual completion of the mission with no degradation in results. Additional information concerning this anomaly is contained in reference 31.

#### 4.3.2 Workshop Solar Array

As a consequence of the meteoroid shield failure at approximately 60 seconds, solar array wing 2 was unlatched and partially deployed, as evidenced by minor variations in the electrical voltages and wing temperatures. Full deployment during the remainder of powered flight was prevented by the aerodynamic forces and acceleration. At the completion of second stage powered flight the four 35,000-pound-thrust retrorockets fired for approximately 2 seconds commencing at 591.1 seconds, and spacecraft separation followed immediately. The effect of retrorocket plume impingement was observed almost immediately on the array wing 2 temperature and on vehicle body rates. Figure 4-22 shows the location and orientation of the retrorockets relative to array wing 2.

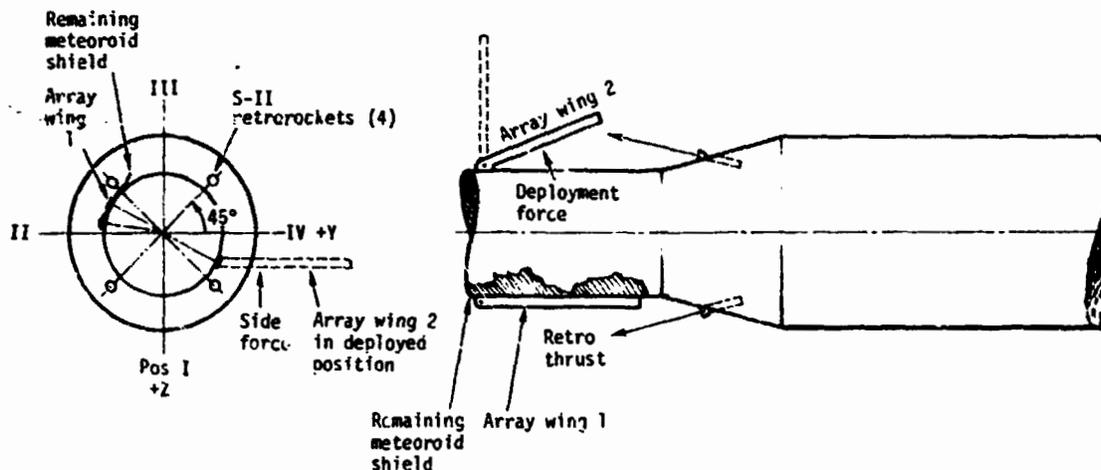


Figure 4-22.- Retrorocket impingement force schematic.

The time sequence of observed changes in the affected measurements is shown in figure 4-23. The response of the vehicle and the corrective action of the attitude control system may be seen in figure 4-24.

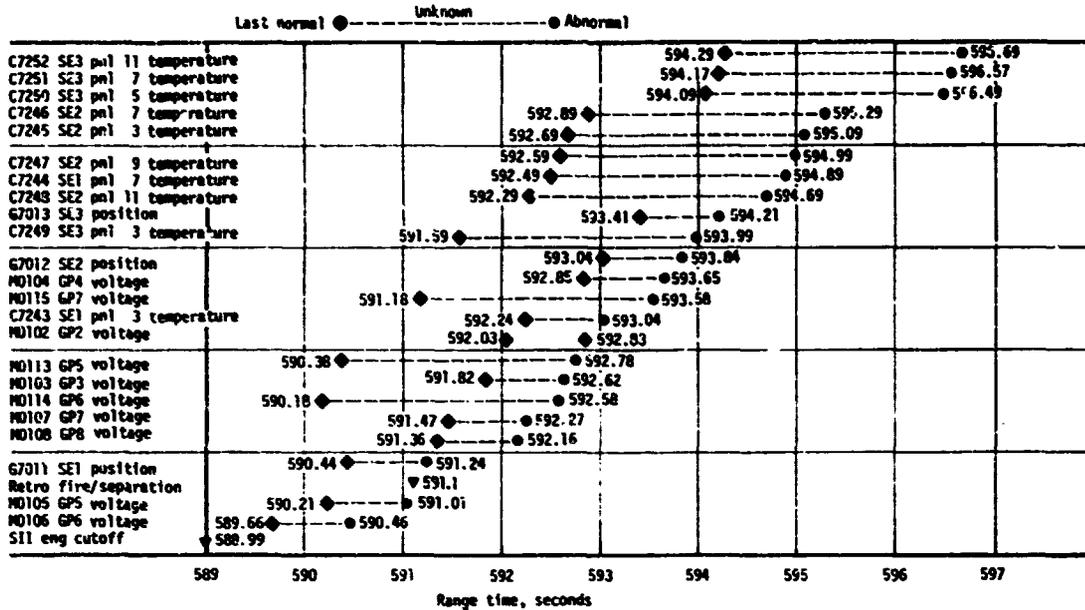


Figure 4-23.- 593-second anomaly time sequence.

- ▽ (591.1) S-II retro fire command and plume impingement on fragments on quadrant II-III
- ▽ (592) Thruster attitude control system operating to null out rates and attitudes induced by retrorocket plume impingement
- ▽ (592.3) Array wing 2 deployed into retrorocket plume and exerts force on workshop
- ▽ (593) End of S-II retro fire
- ▽ (593.4) Initial transfer of wing 2 momentum to workshop
- ▽ (593.9) Final transfer of wing 2 momentum to workshop

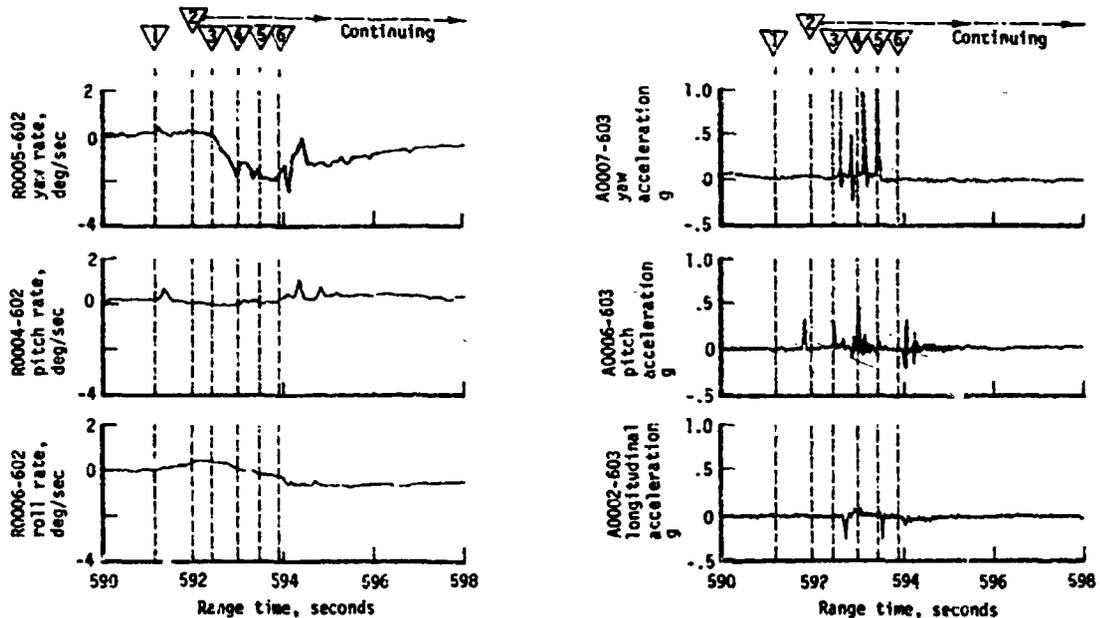


Figure 4-24.- Instrument unit measurements during 593-second period.

The following sequence of events is believed to have occurred. At 591.1 seconds, the retrorocket ignition command was initiated, and plume impingement caused a positive yaw rate buildup and a reduction in the positive pitch rate. At 592.3 seconds, array wing 2 deployed into the plume of the retrorocket in I-IV quadrant and began to affect rigid body rates, causing a large negative roll rate and a small negative pitch rate increment. This impingement force deformed the arm as a cantilever beam in the -Z direction and produced a negative yaw rate which overcame the positive rate previously induced by plume impingement on the workshop. The retrorocket plume impingement also accelerated the deployment rate of array wing 2. These retrorocket exhaust plume impingement forces are shown in figure 4-25.

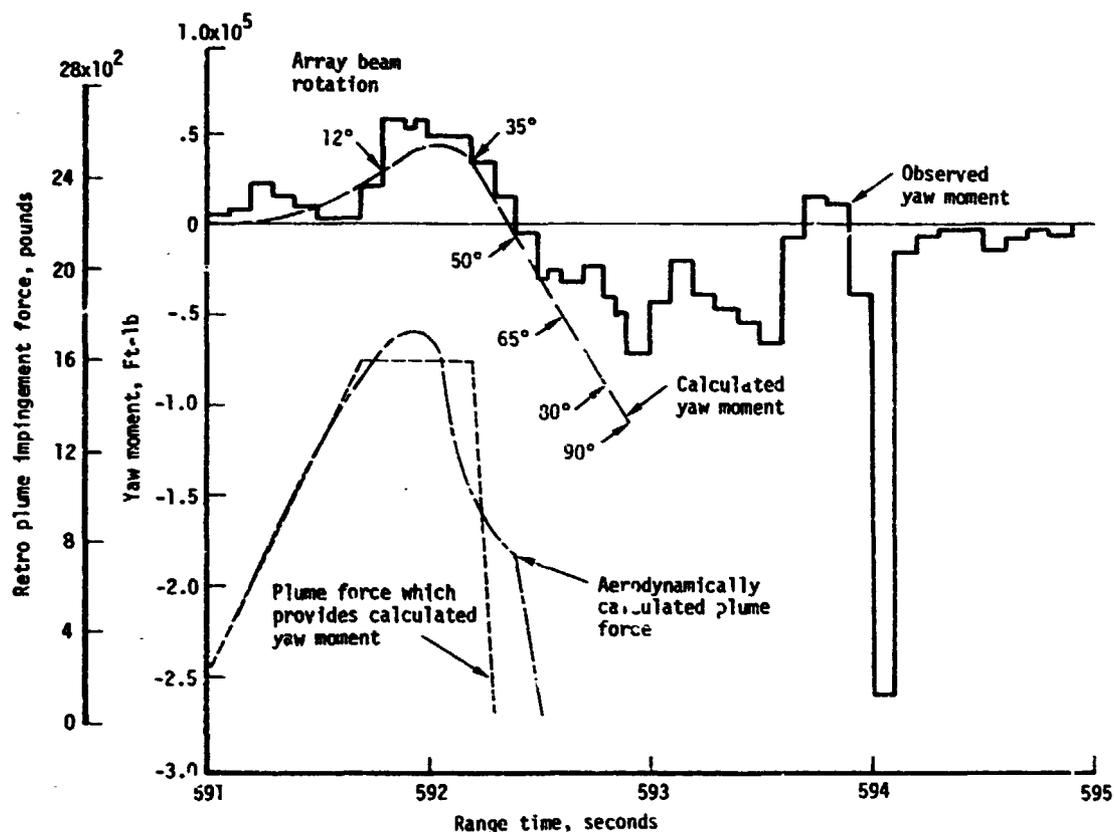


Figure 4-25.- Plume impingement force on solar array wing 2.

At 593.0 seconds retrofire ceased, and the basic rigid body rates became constant. The release of the side force on array wing 2, which had stored strain energy in the wing arm (and in the support point) in the direction normal to the hinge line, caused local structural dynamic activity. This showed up as oscillations in the roll, pitch, and yaw rates. The instrument unit accelerometers also picked up a local transient at this time. Wing 2 continued to deploy. At 593.4 seconds the wing imparted momentum to the vehicle, probably by hitting and breaking the 90-degree fully deployed stops, and at 593.9 seconds it imparted a final kick as it tore completely free at the hinge link. In-orbit photographs show clearly the wing attachment point and the various wires which were torn loose at the interface (fig. 4-9). An analysis of the impingement forces on the wing was made and compared to the force required to produce the observed vehicle motion. This comparison provides a reasonable fit for the first 50 to 60 degrees of wing rotation, as shown in figure 4-25.

The loss of the workshop array wing 2 and the failure of array wing 1 to deploy severely limited the Skylab power in the early days of the mission. After array wing 1 was deployed on Day 25, there was adequate power to complete the mission and meet or surpass all objectives. Additional information concerning this anomaly is contained in reference 31.

#### 4.3.3 Solar Observatory Aperture Doors

The first aperture door malfunction occurred on Day 20 when the X-ray spectrograph door became stuck in the closed position after only 25 cycles. Both motors were used to operate it and it was left in an indicated open position. On Day 25, during an extravehicular activity, it was found to be in a closed position. The crew then latched it in the open position. The ultraviolet scanning polychromator spectroheliometer door first malfunctioned on Day 31, but operation was continued with two motors. After continued intermittent problems, the ramp latch was removed on Day 85 and the door then operated normally with one motor for the rest of the mission, completing 2800 cycles. The X-ray telescope door malfunctioned on Day 35, but two-motor operation enabled use until the ramp latch could be removed on Day 103. It then functioned satisfactorily on a single motor for a total of 800 cycles. On Day 83, the white light coronagraph door telemetry indicated the door was open when analysis showed it closed. Further analysis theorized that the problem was electrical, and the door operated normally for the remainder of the mission, completing 3000 cycles.

The extreme ultraviolet spectroheliograph door was switched to two-motor operation on Day 98 after some opening and closing problems. The ramp latch was removed on Day 103, and one-motor operation was resumed. After other problems required a return to two-motor operation, the door was latched open on Day 226, having completed 400 cycles. The hydrogen alpha 2 door failed to close on Day 118 after 750 cycles. When it became evident during subsequent malfunction procedures that the primary motor circuit had failed, the door was latched open on Day 193. During the third manned period, the ultraviolet spectrograph door began to fail to open and close on one motor after 475 cycles. This door was then electrically inhibited in the open position on Day 231 and remained in that position for the rest of the mission.

The corrective actions described above were supported by analyses and tests. Cycle times for each door were recorded throughout the mission. Spot checks were made from time to time to determine degradation in opening and closing times for the doors. However, there were no trends in the data that would allow prediction of door failure. Operating times required with two motors were approximately 2 seconds less than with a single motor. A 100-cycle test made with two motors operating in the prototype solar observatory showed consistent times of 10 seconds to open and 10 seconds to close. After the 100-cycle test with two motors, single-motor operation was attempted with first the primary and then the secondary motor. During five cycles using the primary motor the opening time was 13 to 14 seconds, but the time to close increased from 21 seconds on the first cycle to 43 seconds on the fifth cycle. The first cycle on the secondary motor took 13 seconds to open, but the door reached the ramp latch on the closed cycle and did not close since the limit switches could not then be triggered. At this point, during a test with two motors operating, the door took 10 seconds to open and 10 seconds to close. The test was resumed after approximately 90 minutes with six cycles using the primary motor; time for the door to open and close increased from 20 seconds on the first cycle to 52 seconds on the fifth cycle. On the sixth cycle,

the secondary motor opened the door in 13 seconds but would not close it, although the ramp latch was reached in 15 seconds. A lubricant was applied to the ramp latch in an attempt to alleviate the problem. The door was opened and closed five times with each motor. The primary motor opened the door in 13 seconds and closed it in 15 seconds. The time to reach the latch was 12 to 12.5 seconds. A final test was made after removing the ramp latch. In a five-cycle test the secondary motor opened the door in 13 to 14 seconds and closed it in 14 seconds, and the primary motor opened the door in 13 seconds and closed it in 14 seconds. In five cycles using both motors, the opening and closing times were a constant 10 seconds.

The ramp latches are aluminum, coated with a bonded solid lubricant. Three that were removed were returned for inspection and analyses. All showed galling on the surfaces. The solid lubricant used is capable of supporting the design load if the substrate is sufficiently hard. However, the aluminum used was not hard enough to support high stress loadings. Moreover, any slight misalignment would have raised the stresses to unacceptable levels for the materials used. Hard anodizing should have been used prior to application of the lubricant.

## SECTION 5 INSTRUMENTATION AND COMMUNICATIONS

The Saturn Workshop instrumentation and communications equipment includes data, command, voice communications, television, onboard monitoring, caution and warning, timing, and rendezvous and ranging systems. Those systems that support the laboratory and those associated with the observatory are referred to separately since their operation is largely independent. The solar observatory equipment is contained within the observatory with the exception of the control and display console located within the docking adapter.

Acquisition and communication of information is a primary function of the Saturn Workshop essential to the control and gathering of performance and experiment data. Figure 5-1 is a simplified diagram of the instrumentation and communications systems. As this figure shows, certain systems use equipment in the command and service module for their operation. More detailed information on the instrumentation and communication systems and their performance can be found in reference 5.

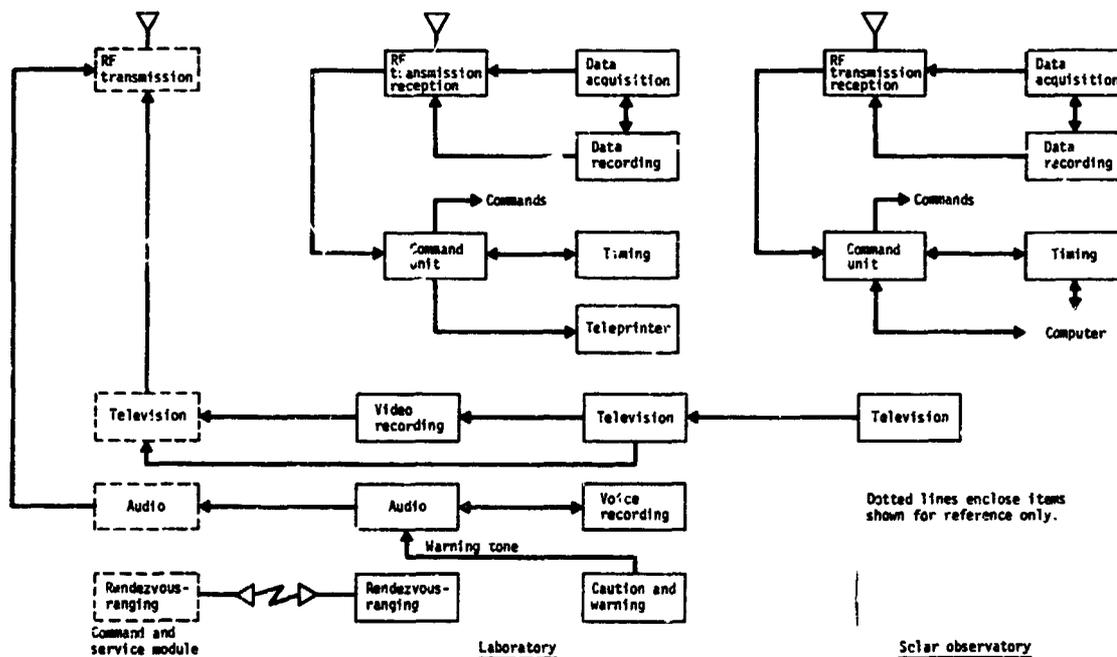


Figure 5-1.- Saturn Workshop instrumentation and communications systems.

### 5.1 DATA SYSTEMS

The data systems collect, code, format, and transmit data throughout the Saturn Workshop to the ground stations. All transmitted data are pulse code modulated. This method reduces the effect of noise on data accuracy during

transmission. Sensors, signal conditioners, multiplexers, transmitters, antennas, and related circuitry are used to perform this operation. The Saturn Workshop data systems sampled 2060 sensors at various rates and coded their outputs into 8- or 10-bit words, producing 123,200 data bits per second. While in contact with the ground stations, about 32 percent of the time, all RF data were transmitted in real time. During the 68 percent of the flight time when there was no station contact, selected data were recorded onboard for subsequent transmission. These data constituted approximately 40 percent of the total data transmitted. The solar observatory, including its data transmission system, is enclosed by the shroud during launch, and measurements required for launch and early-deployment performance information are processed through the laboratory system. Dynamics and acoustic measurements during launch were transmitted through the launch vehicle system, which had analog data transmission capability. Diagrams of the data systems are shown in figures 5-2 and 5-3.

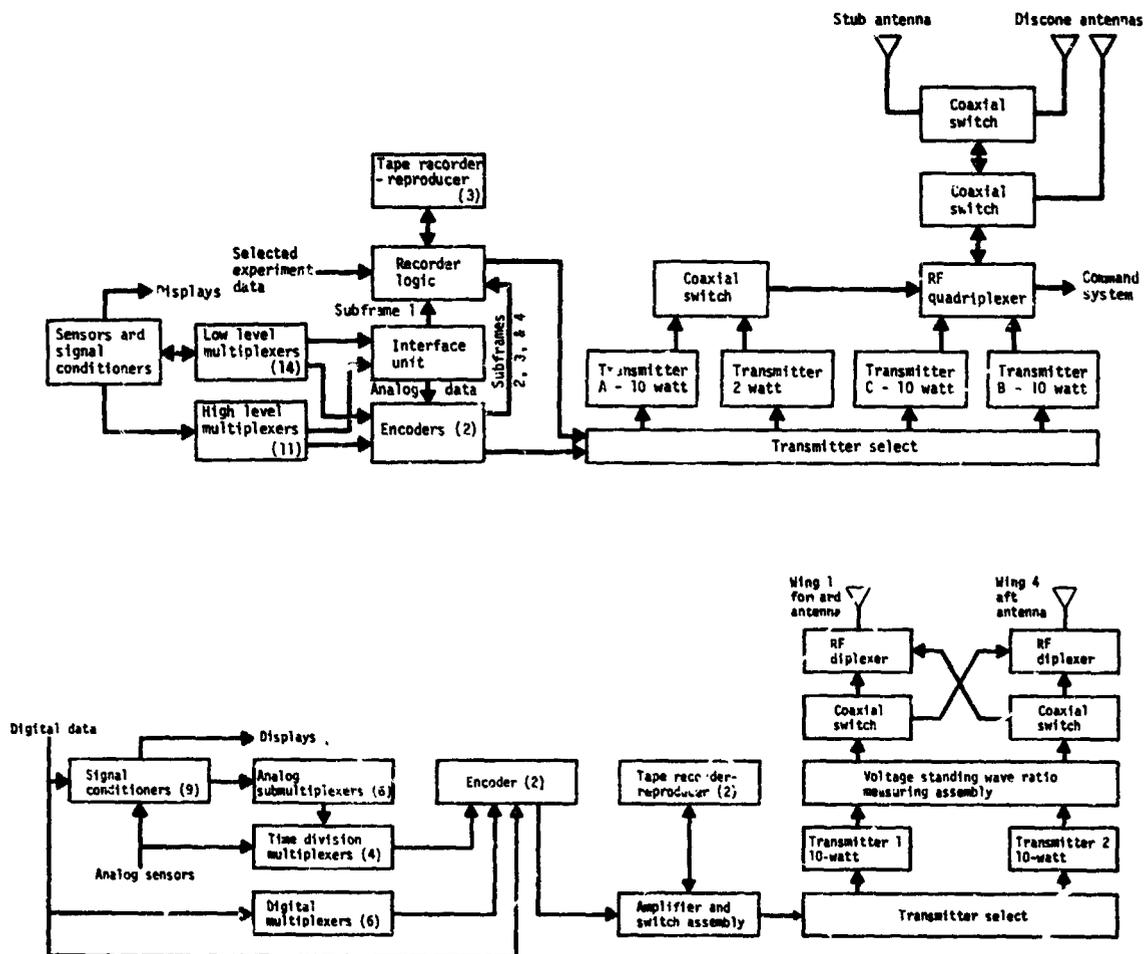


Figure 5-3.- Solar observatory data system.

The laboratory data system was active during the launch phase using a pressurized 2-watt RF transmitter. This transmitter was selected for launch data because the unpressurized 10-watt transmitters used for orbital data would be subject to corona discharge when passing through the upper atmosphere, with resultant data loss. Ten minutes after liftoff, the laboratory tape recorders were activated, and 5 minutes later the dishcone antennas were deployed. Transfer of data from the 2-watt to the 10-watt transmitters was accomplished at 22 minutes after liftoff.

The solar observatory and its solar array wings deployed as planned 25 minutes after liftoff. Its data system was activated 9 minutes later, and all systems indicated proper operation. At 1 hour 44 minutes after launch, after several routine switchings of the transmitters and antennas to obtain the best station coverage, the solar observatory transmitter 1 would not operate on the wing 4 antenna. Operation on the wing 1 antenna was normal, and data transmission for the remainder of the mission was constrained to transmitter 1 using the wing 1 antenna. Transmitter 2 was not affected by this constraint.

The data systems were subjected to the heat extremes during the first un-manned period, but there was no evidence of system degradation from these adverse conditions. The only deviation from normal procedure was to monitor the tape recorder temperatures and to operate the two solar observatory tape recorders alternately to allow a cooling period. The original concept to use one recorder continuously and to reserve the other as a spare unit was modified to operate the backup recorder at least once per day to maintain bearing lubrication and other conditioning. After deployment of the parasol thermal shield, alternating use of the recorders to cool them was no longer necessary; however, the recorders continued to be alternated, with recorder 1 being used approximately 60 percent of the total mission time. There were some data dropouts early in the mission during playback of these recorders to certain ground stations. Evaluation indicated that no problem existed in the airborne system, and ground station procedure changes provided successful data recovery. The laboratory tape recorders, unlike the solar observatory tape recorders which had been designed for total mission life, were originally designed for the Gemini program. These units were updated and refurbished, but their life cycle was far short of the mission duration. Problems in laboratory tape recorder operations were identified and were corrected primarily by replacing the malfunctioning recorder. With one exception, the tape recorders operated beyond their specified life cycles.

Other problems included a laboratory low-level-multiplexer noise signal which appeared on the multiplexers during the third manned period, and one unit which operated intermittently throughout a portion of the mission and subsequently failed. The laboratory telemetry 10-watt transmitter exhibited low radiated power early in the mission. The 2-watt launch transmitter was used to replace this transmitter for the remainder of the mission. In all problem areas, repair or replacement of equipment by the crew or workaround procedures implemented successfully with minimum effect on the mission. No problems were encountered with signal conditioners, power modules, or other components of the data system.

#### 5.1.1 Data Acquisition

The data acquisition subsystems comprise sensors, signal conditioners, multiplexers, encoders, and associated components.

Sensors.- Approximately 2100 separate measurements are acquired, 2060 of which are transmitted to the ground stations. Those measurements not telemetered are displayed onboard or were connected to an umbilical for prelaunch checks.

These sensors located throughout the systems and experiments convert physical characteristics to electrical signals. Various types of sensors are used for temperatures, pressures, positions, flowrates, voltages, currents, acceleration, and various parameters. Table 5-1 summarizes the Saturn Workshop measurements for the mission period, listing the sensors by type, quantity, and performance.

Table 5-I.- Saturn Workshop Measurement Summary

Table 5-I.- Saturn Workshop Measurement Summary

Measurement type	Quantity	Measurement anomalies	Percent recovery	Problem cause
<b>Solar observatory</b>				
Temperature	299	6	97.9	Offscale high; gyro heater failures suspected.
Pressure	15	0	100.0	None
Position	14	0	100.0	None
Event	299	0	100.0	None
Flux	1	0	100.0	None
Angular speed	23	0	100.0	None
Rotational speed	4	1	75.0	Transducer failure.
Voltage	281	0	100.0	None
<b>Totals</b>	<b>896</b>	<b>7</b>	<b>99.2</b>	
<b>Laboratory</b>				
Temperature	153	70	80.2	Lost with 86. 100 mfield and solar
Pressure	105	8	92.4	None
Position	23	2	91.3	None
Event	398	7	98.2	None
Level	10	0	100.0	None
Flow	25	5	80.0	None
Vibration	3	0	100.0	None
Sound	1	0	100.0	None
Voltage	246	42	82.9	None
<b>Totals</b>	<b>1164</b>	<b>134</b>	<b>88.5</b>	
<b>Saturn Workshop Total</b>	<b>2060</b>	<b>141</b>	<b>93.1</b>	

**Signal Conditioners.**- Signal conditioners modify electrical signals from the sensors to make them compatible with the telemetry equipment onboard displays and in some cases supply power for the sensors. Included are power supplies, amplifiers, filters, and other controls.

There were no failures of signal conditioning modules, bus modules, fuse modules, or dc-to-dc power converters. The 5 vdc excitation power converters operated satisfactorily as verified by the stability of reference voltage measurements. Data in table 5-II are typical and indicate that the calibration and reference voltages for the data system were quite stable and accurate.

The measurements displayed onboard were satisfactory except for one minor problem. On Day 86 there was a significant difference in temperature indications between the telemetered data and the onboard display for molecular sieve heat exchangers. Subsequent evaluation determined that the telemetered value was correct and that onboard meters were in error. After some unsuccessful troubleshooting was performed by the crew, the onboard readings were discounted.

Table 5-II. Typical Reference Voltage Data for Selected Samples

Equipment	Voltage			
	Calibration value	Day -4	Launch	Day 135
Remote multiplexer 3	1.068	1.061	1.067	1.052
Remote multiplexer 3	3.955	3.959	3.955	3.938
Remote multiplexer 6	1.055	1.035	1.055	1.058
Remote multiplexer 6	4.125	4.097	4.125	4.106
Multiplexer A1	0.0	0.000	-	0.010
Multiplexer A1	5.0	4.974	-	4.973

**Multiplexer-Encoder.**- The multiplexers accept analog voltage inputs from the sensors and sample each at a preselected rate. Laboratory measurements are sampled at rates from 0.42 to 320 samples per second, depending on specified requirements. A large majority of measurements are made at rates of 0.42, 1.25, or 10 samples per second. Most temperatures vary quite slowly and are sampled at once every 24 seconds. More rapidly changing temperatures, such as those near active thermal control elements, and most pressures are sampled once every 8 seconds. A 10-sample-per-second rate is used for data which require slightly greater sampling rates, and for the majority of discrete events, which allows the determination of event time occurrence to within 0.1 second. Solar observatory data measurements are sampled at rates of one sample every 15 seconds to 120 samples per second, depending on the specific measurement requirements. The majority of these measurements are sampled at 4 or 12 samples per second.

The laboratory data measurements are sampled by 11 high level and 14 low-level multiplexers. High-level multiplexers sample up to 32 analog signals

(0 to 5 vdc) and 40 hilevel signals (0 to 28 vdc) each. Low-level multiplexers sample 32 low-level signals (0 to 20 mvdc) each and amplify the signals by 250 so they fall between 0 and 5 vdc. The outputs of the multiplexers are sent to the encoders if already compatible, or through the interface unit if required. The interface unit provides timing signals to drive the multiplexers and performs third tier switching and integration of their outputs. The integrated multiplexer output is sent to the encoder, which converts the analog signals to an equivalent 8-bit binary number and combines them with digital and synchronizing data for onboard recording or direct transmission to the ground stations.

The solar observatory data measurements are sampled and encoded by six remote analog submultiplexers, four time division multiplexers, six remote digital multiplexers, and two encoders. Each remote analog submultiplexer accepts 60 signals (0 to 20 mvdc) from the signal conditioners. These signals are sampled 12 times per second, amplified to a range of 0 to 5 vdc, and applied on a single output line to 6 input channels of a time division multiplexer.

The time division multiplexers accept 234 usable signals from the remote analog submultiplexers or from the 0 to 5 vdc analog data sources. Each time division multiplexer samples each of its 30 channels 120 times per second. Output is sent to the encoders. Each remote digital multiplexer can accept 100 bits of digital measurement data. These data bits are stored as ten 10-bit words until the encoder is ready to receive them.

The encoders accept both analog and digital data. The analog data from the time division multiplexers are encoded into 10-bit digital words. These words are combined with the digital inputs from the remote digital multiplexers and direct digital data from the computer and solar experiments and arranged into the standard pulse code modulation format, which is applied to either the telemetry transmitters or the tape recorders.

The data systems sampled the onboard parameters continuously 24 hours a day throughout the 272 day mission. This resulted in  $1.3 \times 10^{12}$  data bits output from the workshop encoder and  $1.7 \times 10^{12}$  data bits output from the solar observatory encoder, or a total of  $3 \times 10^{12}$  data bits. While in contact with the ground stations, over  $9.5 \times 10^{11}$  data bits were received by the ground stations in real time and  $6.4 \times 10^{11}$  from the onboard recorders.

The performance of the multiplexers, encoders, and associated electronics in the data systems was well within predicted capabilities. Except for a few instances where a higher sampling rate would have assisted in the resolution of anomalies, with the related measurements selected for these high rates, the data rates chosen provided sufficient information to perform all mission tasks. Data processing and formatting for transmission to the ground and onboard recording were excellent. Problems were encountered in the low-level multiplexers. One laboratory low-level multiplexer exhibited erratic performance on Day 82. Later, sporadic performance was noted and on Day 123 the multiplexer returned to normal operating condition. This multiplexer remained intermittent for the remainder of the mission. The problem affected 28 measurements in the workshop that were not critical to the mission. These multiplexers are subject to some degradation and several units had been exposed to extreme temperatures. Inasmuch as correlating data were available to work around the lost measurements, no troubleshooting or special procedures were initiated.

The first eight channels of another low-level multiplexer showed excessive noise on its output on Day 216, and the first eight channels on each of the workshop low-level multiplexers and nine channels of the programmer exhibited noisy outputs on Day 224. Table 5-III summarizes the performance history of the multiplexer-encoder components.

Table 5-III.- Performance History of Multiplexer-Encoder Subsystem

Component	Quantity used	Anomalies	Problem mode
<u>Laboratory</u>			
Encoder	2	0	None Intermittent throughout mission; steering diode failure suspected (1). Noisy; second level tier switch failure (1). Noise; first 8 channels of each unit. Reference voltage problem suspected (6).
Low-level multiplexers	11	8	
High-level multiplexers	14	0	
<u>Solar Observatory</u>			
Encoders	2	0	
Multiplexers	4	0	
Remote analog submultiplexers	6	0	
Digital multiplexers	6	0	

The loss of the sensors caused by the failure of the meteoroid shield and solar array wing, the individual sensor failures, and the multiplexer failures affected 141 of the total 2060 measurements. This represents a 93 percent data recovery rate at the end of the mission. However, the majority of the multiplexer problems occurred during the third manned period so that the actual percentage of recovered data was greater for a long period of time (table 5-I).

#### 5.1.2 Data Recording

Tape recorders store selected data when the Saturn Workshop is not in contact with any ground station. Recorder playback is scheduled over selected stations, dependent upon the amount of data stored and the time duration of station contact. The data recording systems comprise five tape recorders, together with associated interface units, power supplies, and controls.

Three 2-track tape recorders are used in the laboratory data system. The tape recorders record voice only on one track, and pulse code modulated data only on the other track. The pulse code format is based on a master frame rate of 40 per second. Portions of the master frame time (0.025 second) are broken down into five additional subframes by the multiplexers. Subframes 1 through 4 may be recorded, but subframes data are only available in real time. The pulse coded data are recorded at a rate of either 5120 bits per second, which is every 10th sample of the encoder output, or 5760 bits per second, which is the output of the experiment data system. Each of the 3 recorders is capable of storing up to 3 hours of information and playing back at a speed 22 times faster than recording speed: 112.64 or 126.72 kilobits per second.

The solar observatory data recording system includes an interface unit, a memory unit, dc-to-dc power converters, and two tape recorders. The system

accepts a parallel 72-kilobit-per-second data format and synchronization signals from the encoders and converts them into a 4-kilobit-per-second data stream for recording on tape.

The interface unit selects the measurement words identified by the memory unit. The selected words are stored in the memory. On the proper read command, data are transferred from the memory to the interface unit, where the proper tape storage format is generated and applied to the tape recorder input.

The maximum record time for each tape recorder is 90 minutes, which is approximately the time of one Skylab orbit. Playback time is 5 minutes, or 18 times the record speed, increasing the 4-kilobit rate to 72 kilobits per second, which is the same as the real-time rate. Only one tape recorder can be operated in the record or the playback mode at any given time because of an electrical interlock; however, both recorders may operate simultaneously in opposite modes.

Four spare laboratory recorders were launched with the Saturn Workshop, and the laboratory data recording and playback were accomplished as planned. During the first manned period two of the operating recorders experienced malfunctions. The first recorder failed and was replaced on Day 26 with a spare unit. The second problem occurred while the first crew was preparing to return, and inasmuch as the two operating recorders were sufficient for data storage during the unmanned period, replacement was delayed until the arrival of the second crew. Two more spare units were brought onboard by this crew, and the failed unit was replaced on Day 79.

A recorder had numerous bit errors and loss of synchronization on Day 123, and was replaced. Subsequent troubleshooting by the crew revealed that the tape path was incorrect. The tape path was corrected and the heads and idlers were cleaned. The recorder was stowed for possible use as a spare. Another tape recorder was replaced on Day 127. Although the recorder was still performing properly it was replaced before the third unmanned period because it had accumulated 1500 hours and specified life is 750 hours. It was replaced to preclude a failure during the unmanned period when the recorder could not be replaced by the crew. A fourth tape recorder failure occurred on Day 252 and the unit was replaced. Another recorder was replaced on Day 253. Although this unit was performing properly, it had exceeded its expected operating life by more than 800 hours, and was replaced as a precautionary measure.

The tape recorder utilization plan called for a total of 1217 hours during the launch, activation, and first manned period and 1652 hours during the second unmanned and manned periods. The laboratory tape recorders recorded 1480 hours of data through the end of the first manned period. This was approximately 260 hours over planned use. The major cause of this time overrun was the 10-day delay in the launch of the first crew. Actual use during the second period was 2188 hours. The additional 536 hours over planned use was due mainly to the increased use by Mission Control for data analysis and system troubleshooting. During the third unmanned and manned periods the recorders operated 6320 hours, longer than they operated for the previous periods combined. This was largely because these periods were longer (52 days unmanned and 84 days manned).

There were approximately 714 data playbacks to the ground stations during the first manned period, 1160 playbacks during the second unmanned and manned periods and 1176 playbacks during the third unmanned and manned periods. The recorders in general performed well. The specified operating time of 750 hours

for each totaled 5250 hours for the seven recorders. Two additional recorders were supplied during the mission, raising total capability to 6750 hours. Actual operating time for the nine recorders during the mission was 9884 hours, exceeding requirements by more than 3100 hours. At the end of the mission, two of the three remaining tape recorders had exceeded specified life by 249 hours, and all recorders were operating normally. Ground recovery of the delayed time data from the recorder playbacks was excellent, and the delayed time voice was consistently good.

Table 5-IV provides a summary of laboratory tape recorder use for the mission. The table identifies tape recorder units by serial number and shows where they were used in the airlock by position number. Since recorders had been space

Table 5-IV.- Laboratory Tape Recorder Performance History

Position number	Recorder serial number	N=New R=Refurbished	Use time, hours					Performance
			Vendor		Operation		Total	
			Rework	Test	Test	Flight		
1	13	R	280	535	62	617	1214	Failed Day 26 Failed Day 40 Failed Day 252 *
	22	R	230	305	89	266	660	
	32	N	-	145	76	1229	1450	
	21	R	220	424	56	338	818	
2	30	N	-	138	31	1330	1499	Replaced Day 127 due to excessive use--no failure** *
	34	N	-	219	9	703	931	
3	28	N	-	270	22	735	1027	Noisy--replaced Day 123** Excessive use-- erratic operation. Replaced Day 253** *
	23	R	100	195	46	1578	1819	
	14	R	90	206	142	110	466	

\* Operating at end of mission.  
\*\* Available as inflight contingency spare.

qualified for the Gemini program, some were reclaimed from that program and refurbished for Skylab and some new units were also obtained. Figure 5-4 shows the life performance of the recorders. The upper curve shows the total capability of the recorders in hours, based on a life of 750 hours per recorder. The initial capability of 5250 hours for the seven onboard recorders increased to 6750 hours when the second crew carried up two additional recorders. The other variation in capability is an increase when the recorders exceed a useful life of 750 hours and a decrease when a recorder fails to achieve predicted capability. The middle curve shows the total operating time, which includes vendor and ground testing and checkout before the Saturn Workshop launch. The lower curve is the total cumulative hours of inflight operation relative to mission time.

The solar observatory data recording system performed flawlessly throughout the mission. Control circuitry performed on command, and data playbacks were performed over selected ground stations more than 4300 times. During the early period of the mission when Skylab was flown in the various non-solar-inertial attitudes, the solar observatory tape recorders lost the protection of the solar observatory sunshield and were exposed to direct solar radiation. The high temperatures experienced during this period made continuous monitoring of the recorder temperatures necessary so that each recorder could be turned off when critical temperatures were observed.

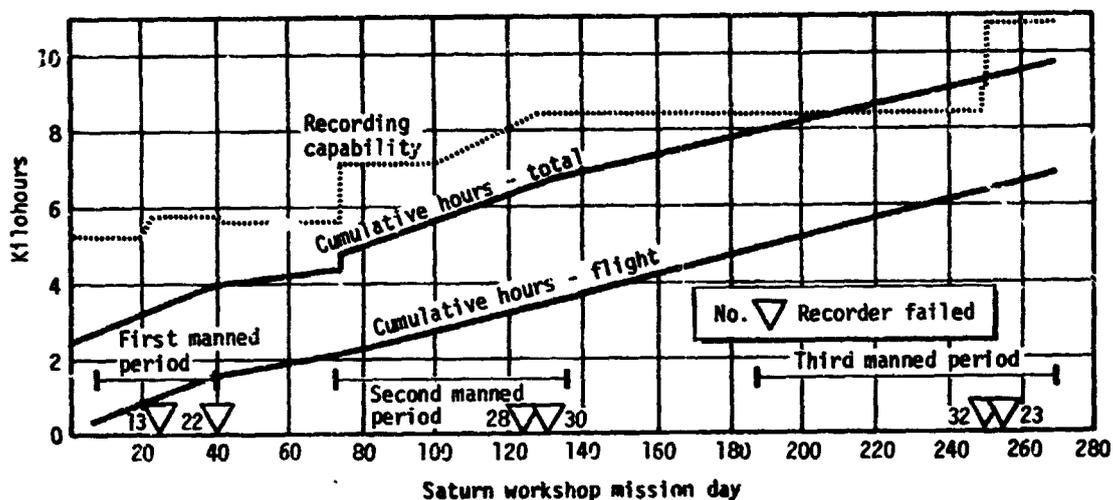


Figure 5-4.- Laboratory tape recorder life performance.

There was no evidence of system degradation from the excessive heat or from other adverse conditions. During some early data transmissions, primarily over the Vanguard receiving station, recorded data recovery tapes contained numerous data dropouts. Investigation indicated that there was no problem in the orbiting system and that the data were being properly decommutated at the ground stations. The probable cause was high electromagnetic interference surrounding the ground station. The Vanguard ground station is a tracking ship which was docked at Mar del Plata, Argentina. The Vanguard tracking ship was relocated away from the docks, which alleviated the problem.

The recorders were designed for 5000 hours operational life each. At the end of the mission, the recorders had operated 6340 hours out of a predicted mission use of 6956 hours. A breakdown of solar observatory tape recorder use is given in table 5-V.

Table 5-V.- Solar Observatory Tape Recorder Use

Recorder number	Test time, hours	Mission time, hours	Total, hours
1	219	3750.5	3969.5
2	454	2589.3	3043.3
Totals	673	6339.8	7012.8

### 5.1.3 RF Transmission

Saturn Workshop data were downlinked during launch by the 2-watt transmitter. During the mission it and five 10-watt transmitters were used with their associated RF equipment operating in the VHF band. The flow of data was maintained by providing the maximum number of ground stations that could be economically accommodated and by using transmitters with sufficient output power driving antennas of the correct type and location on the vehicle structure to provide adequate antenna coverage and signal gain. Figure 5-5 shows the antenna locations. Several of these antennas are shown in Figure 4-6 also.

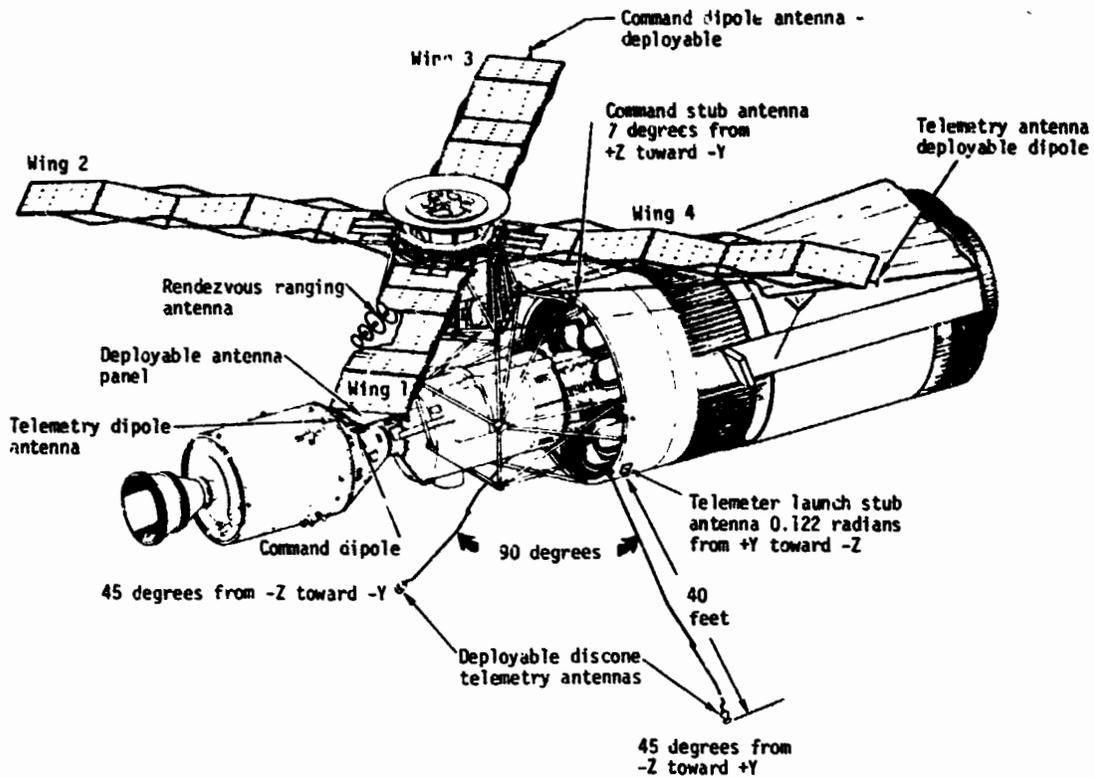


Figure 5-5.- Antenna locations.

A special computer program was used to generate tracking data throughout the Skylab mission. Data were generated for tracking locations at St. Louis and at Marshall Space Flight Center, in addition to Spaceflight Tracking and Data Network stations. Tracking data were computed for approximately 2-week periods (300 revolutions), and, at each such interval, current trajectory parameters were used to update the computer orbital model. This updating procedure plus spot checks against other sources of data ensured that the tracking data used in the model update had a high degree of accuracy. A summary of tracking data provided for the complete Skylab mission was compiled to determine the actual coverage provided by the ground station network and the validity of pre-mission predictions. Ground station contact time is summarized in table 5-VI.

**Laboratory antennas.-** A flush-mounted stub antenna for use during launch through orbital insertion and two disccone antennas mounted on extendible booms which are deployed after shroud separation compose the laboratory data antenna subsystem. Antenna coverage is defined as the percentage of total antenna pattern which yields gain levels high enough to accomplish positive RF link margins at a maximum slant range of 1300 nmi. The laboratory telemetry antennas produced this margin of gain levels over 95 percent of each disccone antenna pattern and 93 percent of the stub antenna pattern when a 10-watt signal was radiated.

The 2-watt transmitter power output provided positive circuit margins over 80 percent of the disccone antenna patterns and 68 percent of the telemetry stub antenna pattern at the normal 1300 nmi range. The reduction of power from 10

Table 5-VI.- Saturn Workshop Contact Summary

Coverage	Contact time	
	Minutes	Percent
Station		
Vanguard Ship	15,938	
Bermuda	14,616	
Madrid	13,906	
Goldstone	13,053	
Honeysuckle Creek	12,293	
Merritt Island	11,958	
Texas	11,658	
Canary Island	11,056	
Carnarvon	11,028	
Hawaii	10,294	
Guam	9,018	
Ascension Island	8,533	
Total contact	143,351	36.88
Station overlap	17,207	4.42
Cumulative nonoverlapping station coverage	126,144	32.46
Time of no contact	262,512	67.54
Mission duration	388,656	100.00
Predicted coverage		
First unmanned and manned periods		33.2
Second unmanned and manned periods		33.3
Third unmanned and manned periods		32.7

watts (40 dbm) to 2 watts (33 dbm) yields a ratio of 1:5, which corresponds to a 7 decibel loss. To maintain the circuit margin which the 10-watt transmitter provided, the attenuation of space (distance) must be reduced for the 2-watt transmitter by 7 decibels. This reduction converts the 1300 nmi maximum to approximately 600 nmi. At slant ranges of 600 nmi or less, antenna gain levels that will still produce positive circuit margins are achievable over 95 percent of the discone antenna patterns.

Performance predictions for the laboratory telemetry links are presented in figure 5-6. The figure indicates that an approximately +8 decibel circuit margin should be expected from the discone links at maximum slant range. A more realistic average margin to expect would be associated with a medium range of 650 nmi or a margin of +15.5 decibels. At the top of the circuit margin range of values would be a margin increase of +23 decibels associated with maximum slant range loss. These values are achievable with laboratory antenna gains which exist over 75 percent of the antenna patterns, so a small number of passes can be expected with margin values outside the +8 to +23 decibel range. Assuming ground station receiver sensitivities of 108 decibels below 1 milliwatt, the above range of circuit margins would indicate that most passes should yield received signal strengths between 100 and 85 decibels below 1 milliwatt.

Laboratory RF System.- Data blackout and possible damage to RF components were avoided by using the laboratory 2-watt transmitter during the launch period, since the relatively higher power output of the 10-watt transmitters would be more likely to cause corona discharge at the upper atmosphere regions. A stub antenna was used until the two discone antennas could be deployed. Laboratory transmitter A began continual real-time data transmission when the 2-watt transmitter was shut down after 22 minutes. Transmitters B and C were used periodically as planned to

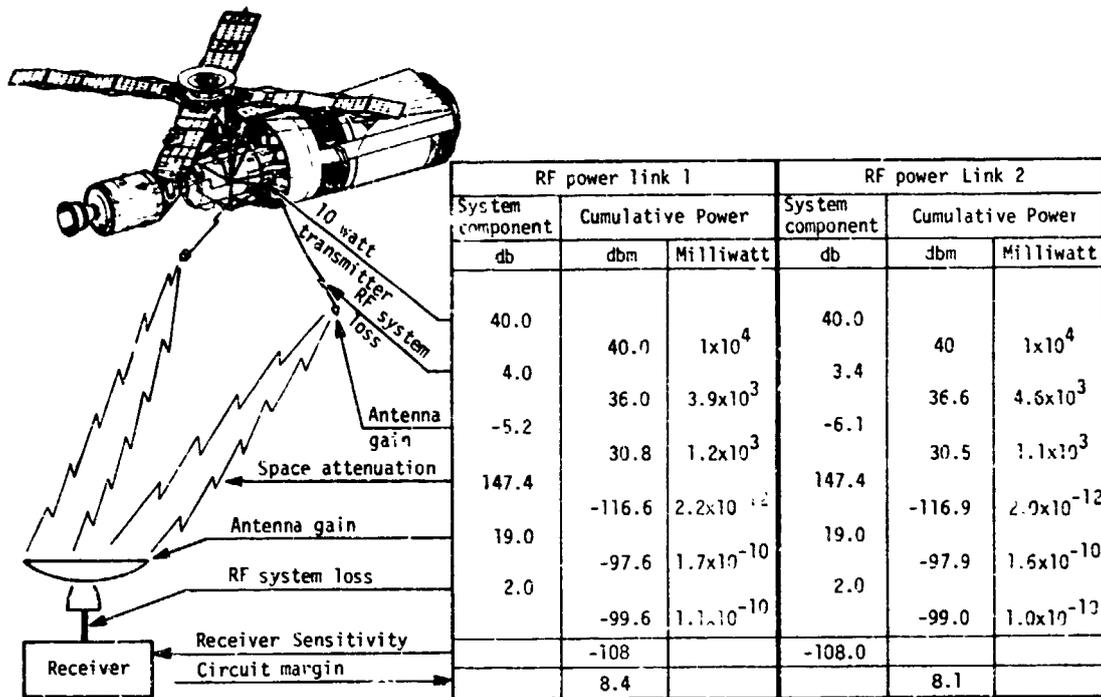


Figure 5-6.- Laboratory telemetry link calculations.

provide transmissions of recorded data. When two laboratory tape recorders are played back simultaneously, separate transmitters are required. During extravehicular activity operations on Day 25, a loss of real-time telemetry signal from transmitter A was noted. This condition was due to corona in the quadriplexer caused by venting of the airlock. The 2-watt transmitter was reactivated at this time. Approximately 6 hours later, the real-time telemetry transmissions were reconfigured for transmitter A which operated successfully until Day 30. On Day 30, the received signal strength from transmitter A indicated a 12- to 14-decibel decrease. Analysis indicated that the transmitter A RF power amplifier had failed. This conclusion was based on a review of case temperature, bus voltage data, and simulation tests. The 2-watt transmitter was again activated, and its signal strength was 2 to 3 decibels greater than that of transmitter A. Transmitter B was then used for the real-time telemetry. The 2-watt transmitter was used for real-time telemetry during times when both transmitters B and C were required for tape recorder playback. Transmitter C was used only for transmissions of recorded data. This procedure was followed for the remainder of the mission. The use of the 2-watt transmitter required a reduction of the predicted circuit margins of approximately 7 decibels.

The discone antennas were used for all laboratory RF transmissions after orbital insertion. Selection between discone antennas 1 and 2 was made approximately 5500 times throughout the mission to optimize antenna coverage. The indicator for the change between the 2-watt transmitter and transmitter A failed on Day 43; however, performance analysis revealed that the switch was operating normally. Telemetry transmitter C failed to respond to commands over one station but responded to the same command over the next ground station on Day 202 and Day 220. The cause was either an intermittent relay contact or a malfunctioning output power circuit. The average power outputs of the laboratory telemetry transmitters for the mission are shown in Table 5-VII.

Table 5-VII.- Laboratory Telemetry Transmitter Average Power Output

Transmitter	Average power output, watts	* Averaged to time of failure
2-watt	1.0	
10-watt A	7.5*	
10-watt B	9.0	
10-watt C	12.15	

Ground station telemetry receiver signal strength data were analyzed to verify laboratory RF system performance. The data analyzed were receiver automatic gain control voltage profiles received from ground sites. The automatic gain control voltages are a direct indication of telemetry link signal strength. These data were compared with circuit margin predictions of link performance.

Signal strength data for short periods of time were examined from several of the ground stations to determine and log the average signal strength and also the high and low peaks experienced during the station passes. These data were summarized in table 5-VIII.

Table 5-VIII.- Laboratory to Ground Station Telemetry Signal Strengths

Site	Revolution	Signal strength levels, decibels below 1 milliwatt						Maximum elevation, degrees
		Line A		Line B		Line C		
		Average	Range	Average	Range	Average	Range	
Goldstone	314	88	82 to 102	87	82 to 89	87	82 to 89	53
	316	100	92 to 107					8
	613			92	90 to 102			24
	815			99	91 to 107			8
	812			94	90 to 103	93	90 to 99	20
	815			97	88 to 101			30
	1180	164	99 to 107	90	89 to 104	95	89 to 100	95
	1183			99	95 to 104			11
	1521	103	100 to 107	93	88 to 100	96	90 to 98	44
	1526			98	92 to 98			32
	1757			93	86 to 98			81
	1768			97	94 to 104			9
	2290			100	94 to 104			9
	2292			95	91 to 100	92	89 to 98	24
	2217			99	95 to 107			8
2719			91	85 to 98	90	82 to 96	69	
3102	103	98 to 107	95	91 to 102	96	92 to 105	19	
Texas	274	99	92 to 110	99	93 to 103	100	95 to 101	3
	276	95	85 to 105	95	92 to 100	99	95 to 105	24
	503	104	98 to 110	92	85 to 105	91	87 to 99	37
	599			91	89 to 99	95	89 to 100	21
	1450					98	94 to 103	10
	1454			89	77 to 99	95	84 to 102	58
	1824			95	92 to 100	98	92 to 107	19
	2468			95	92 to 94	98	92 to 103	10
	261			93	92 to 103	91	82 to 97	60
	2901			93	84 to 97			57
	2464			95	92 to 103			9
	3356			95	91 to 98			3
	3367			95	87 to 104	94	87 to 105	11
Bermuda	457			93	90 to 105			4
	460			90	84 to 93	92	84 to 98	24
	1220			101	93 to 107	95	89 to 107	4
	1225					93	90 to 96	64
	1452			94	96 to 98			26
	1453			94	89 to 102			26
	1740	101	97 to 107	96	98 to 99	95	89 to 99	16
	1752	98	94 to 103	92	85 to 97	90	84 to 95	57
	2088			92	80 to 104	93	80 to 99	80
	2091			94	95 to 107			5
	2301			92	88 to 93	93	88 to 98	60
	2302			100	95 to 104			5
	2686			98	92 to 107	96	92 to 100	9
	2699			95	92 to 104			34
	2668	103	98 to 107	96	90 to 104	96	93 to 105	8
3073			91	85 to 101			74	

Solar Observatory RF System.- Two VHF transmitters produce 10-watt frequency modulated outputs in the 225 to 260 megahertz range with a peak deviation of 72 kilohertz. Input switching permits either transmitter to transmit real-time or recorded data or both transmitters to transmit the same type of data simultaneously.

A voltage standing wave measuring assembly measures the incident and reflected RF power at the output of the transmitters. The transmitter outputs are fed to the antennas by means of two coaxial switches and two diplexers. The switches select the antenna or antennas to be used, and the diplexers provide maximum RF power transfer by maintaining an impedance match between the transmitters and the antennas.

One antenna is mounted on the tip of solar array wing 1 and the other on solar array wing 4. These are dipole antennas and provide complementary radiation pat-

terns. They are used singly or in pairs; either transmitter can feed either, but not both, of the antennas simultaneously.

The telemetry antenna on solar array wing 1, when driven by the 10-watt transmitters, produces an antenna gain over 84.5 percent of its pattern, which results in a positive circuit margin at the ground station receivers at slant ranges up to 1300 nmi. The antenna on wing 4 produces such antenna gains over 93 percent of its pattern.

Performance predictions for the solar observatory telemetry links are presented in figure 5-7. The figure indicates that an approximately +6 decibel

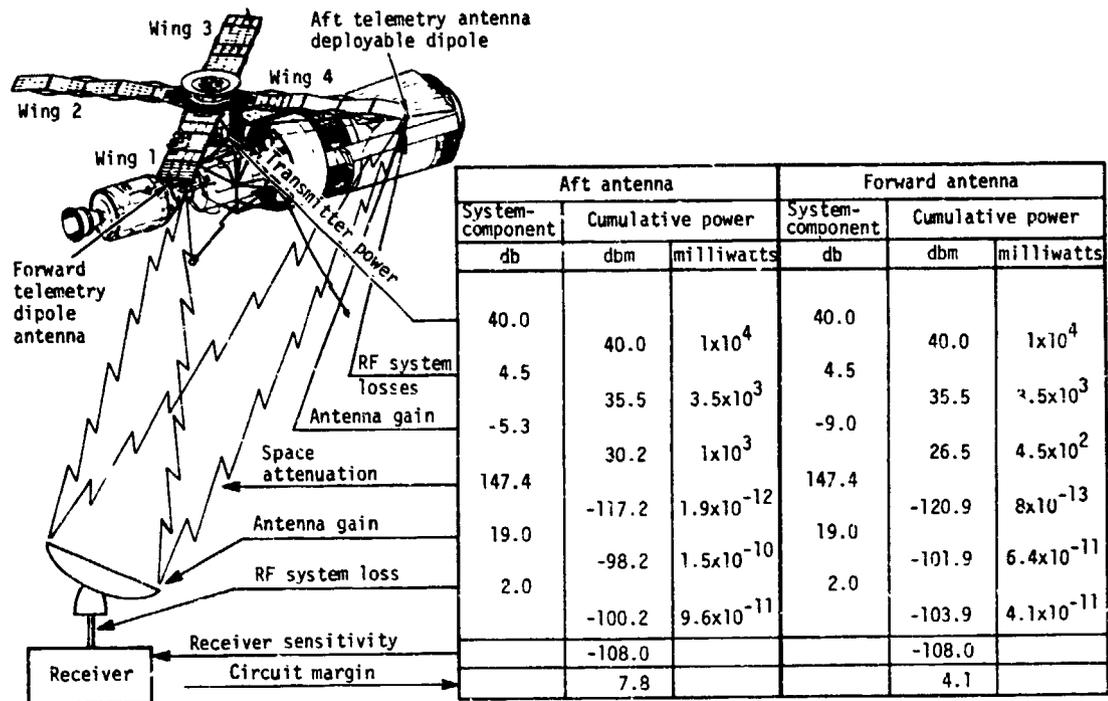


Figure 5-7.- Solar observatory telemetry link calculations.

circuit margin should be expected from the solar observatory links at 1300 nmi slant range. A more realistic average margin to expect would be associated with a medium range of 650 nmi, or a margin of +13.5 decibels. At the top of the range of values would be a circuit margin increase of +21 decibels associated with minimum slant range loss. These values are achievable with antenna gains which exist over 75 percent of the antenna patterns, so a small number of passes can be expected when circuit margin values extend outside the +6 to +21 decibel range.

Assuming ground station receiver sensitivities of 108 decibels below 1 milliwatt, the above range of circuit margins would indicate that most passes should provide signal strengths between 102 and 87 decibels below 1 milliwatt at the receiver with an average level of 94.5 decibels below 1 milliwatt being quite common. The RF transmission system performance was satisfactory throughout the mission. One minor problem was encountered 1 hour 44 minutes after liftoff. After several transmissions and switching operations had been performed, transmitter 1 was switched to the wing 4 antenna and a high reflected power was indicated. Investigation indicated the most probable cause to be a failed coaxial switch. Transmitter 1 was switched to transmit through the forward antenna, on wing 1, for the remainder of the mission.

Power outputs of both transmitters, as well as modulation characteristics and carrier deviation, were within specified ranges throughout the mission. Output power for transmitters 1 and 2 was 13.6 and 14.4 watts, respectively, throughout the mission. Signal strength data for the RF downlink were analyzed for selected ground stations and station passes throughout the mission. Table 5-IX is a summary of this data.

The crew deployed a thermal shield on Day 13. The shield consisted of a large area of aluminized cloth and gave two antenna pattern effects. First, it presented a physical blockage over small sectors of the antenna patterns, which

Table 5-IX.- Solar Observatory to Ground Station Telemetry Signal Strengths

Site	Revolution	Signal strength levels (decibels below 1 milliwatt)				Maximum elevation, degrees
		Link 1		Link 2		
		Average	Range	Average	Range	
Goldstone	114	84	80 to 87	87	82 to 95	53
	316			97	95 to 105	8
	388	98	90 to 107	97	92 to 107	9
	613	95	97 to 99	95	90 to 101	24
	615	97	91 to 101	95	90 to 104	8
	812	100	91 to 107	95	92 to 107	20
	816	94	90 to 103	92	84 to 105	26
	1180	97	88 to 100	93	89 to 102	85
	1183	100	91 to 107	97	95 to 104	11
	1422	101	89 to 107	90	78 to 97	64
	1424	100	94 to 104	98	93 to 104	7
	1767	95	88 to 107	92	82 to 105	81
	1768	100	95 to 107	95	91 to 102	9
	2288	96	87 to 107	91	87 to 95	40
	2391	95	95 to 107	99	94 to 107	9
	2717	100	97 to 105	99	93 to 105	8
	2720	96	92 to 98	103	97 to 107	6
	3100	103	95 to 107	98	91 to 107	7
	3102	92	92 to 99	95	89 to 103	19
	Texas	270	92	84 to 100	92	84 to 100
272		95	91 to 100	95	91 to 102	2
502		91	87 to 101	91	87 to 103	16
560		100	90 to 107	92	87 to 105	27
1430		98	92 to 102	98	94 to 105	10
1454		93	85 to 104	90	82 to 100	58
1832		89	85 to 95	92	85 to 98	20
1833		98	92 to 107	92	88 to 105	26
2700		96	91 to 107	94	89 to 107	12
2704		99	98 to 107	93	86 to 103	43
3356		95	92 to 98	95	91 to 99	3
3367		98	92 to 105	94	87 to 101	31
Bermuda		455	93	84 to 104	93	83 to 104
	457	98	95 to 103	96	93 to 100	4
	1225	95	92 to 96	95	91 to 97	64
	1226	95	90 to 100	90	85 to 95	4
	1452	102	93 to 107	99	95 to 107	6
	1453	95	88 to 107	98	89 to 105	26
	1750	105	98 to 107	98	94 to 107	5
	1752	93	87 to 103	93	86 to 103	52
	2088	92	81 to 101	90	81 to 101	30
	2090	100	97 to 103	100	97 to 104	4
	2301	100	93 to 107	93	85 to 100	1
	2306	95	84 to 107	90	84 to 98	54
	2688	98	96 to 107	100	91 to 107	7
2690	98	90 to 107	96	89 to 103	20	
3071	98	91 to 107	98	91 to 107	4	
3073	89	83 to 98	91	81 to 105	74	

reduced antenna coverage, and secondly, it modified antenna patterns which were previously measured to determine antenna selection during the mission. Neither of these effects was considered greatly detrimental. The reduction in coverage to the solar observatory antennas on wing 3 (command antenna), wing 4 (telemetry antenna), and, to a lesser extent, wing 1 (telemetry and command antenna) was less than 3 percent. The amount of antenna pattern distortion due to reflections from the thermal shield could not be determined because of the multiplicity and randomness of the variables involved, but it was estimated to have been minimal. The laboratory dishcone antennas were on long booms below the vehicle and were not affected by the thermal shield.

## 5.2 COMMAND SYSTEMS

The command systems receive and decode more than 1000 distinct digital commands for three essential functions. These commands are used for system control and operation, for updating the time reference system, and for messages containing information and instructions for the crew

that are produced by an onboard teleprinter. These commands are primarily transmitted from the ground stations; however, the crew also may initiate control commands from the control and display panels. The system uses complete redundancy to ensure reliability.

### 5.2.1 Laboratory Digital Command System

Two command receiver-decoders, four relay units, a command relay driver, a coaxial switch, and a stub antenna are used. In addition, the receivers share the quadriplexer, switches, and antennas used by the laboratory data transmission system. Figure 5-8 is a diagram of this system.

Each command receiver-decoder contains two receivers and one decoder section. The primary receiver-decoder unit has a sensitivity of 104 decibels below 1 milliwatt. The secondary receiver-decoder unit has a sensitivity of 98 decibels below 1 milliwatt. The two receiver-decoder units are of different design and thus have different sensitivity characteristics. The primary and secondary receiver-decoder sets are redundant. Each receiver-decoder has a unique address, which allows the ground controllers to select the receiver they wish to command. This two-address control was chosen to enhance the reliability of the system by providing a fully operational system should one unit fail. Control of the power to the units is primarily by ground command; however, should one receiver indicate improper performance, internal monitoring automatically switches the units. Commands are transmitted from the ground stations to one of the receiver-decoders. The outputs of the receivers are summed and sent to the decoder section. A verification pulse is returned to the telemetry system for each valid message correctly received and

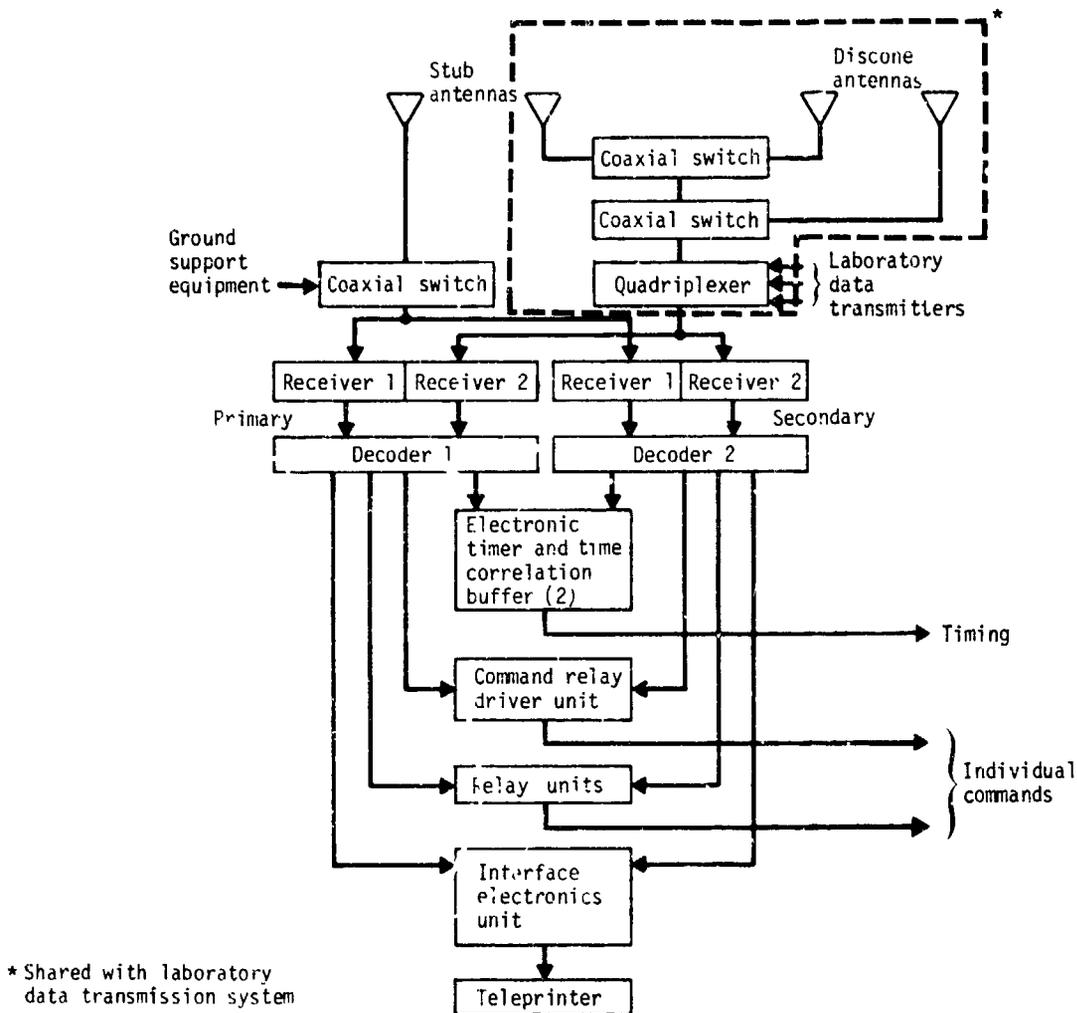


Figure 5-8.- Laboratory command system.

decoded. The decoder sends digital data to the teleprinter, the time reference system, or the command relay driver units, or sends discrete pulse commands to a relay in one of the module units.

The command relay driver unit converts the digital output of the decoder into additional real-time commands. Two identical subunits are paralleled to provide a common output of 480 pulse commands which control relays. The command relay driver unit also provides a digital output to the telemetry system indicating that the specific relay command was processed.

Each of the 4 relay units contains 8 latching relays, which provides a total of 32 real-time channels. Each relay provides an output to the telemetry system to indicate its position.

The digital command system operated successfully throughout the mission, processing more than 100,000 commands. Both primary and secondary digital command subsystems were powered up from launch to Day 4. The secondary subsystem was powered down from Day 4 to Day 12 to conserve power. The secondary subsystem was again activated on Day 12 to serve as backup for the first crew rendezvous and then powered down on Day 13; it remained powered down through Day 140. The

secondary subsystem was powered up on Day 140 because the secondary electronic timer was operating and it was desired to maintain the digital command system and electronic timer on separate buses to avoid a single point failure possibility. The primary subsystems were reactivated on Day 190 for the remainder of the mission. A command was sent on Day 182 to remove the fast forward command for tape recorder 2, but no response was observed. Telemetry data indicated that the control relay for this function did not change its position. The relay was successfully reset on Day 183, and the fast forward command was not used after that.

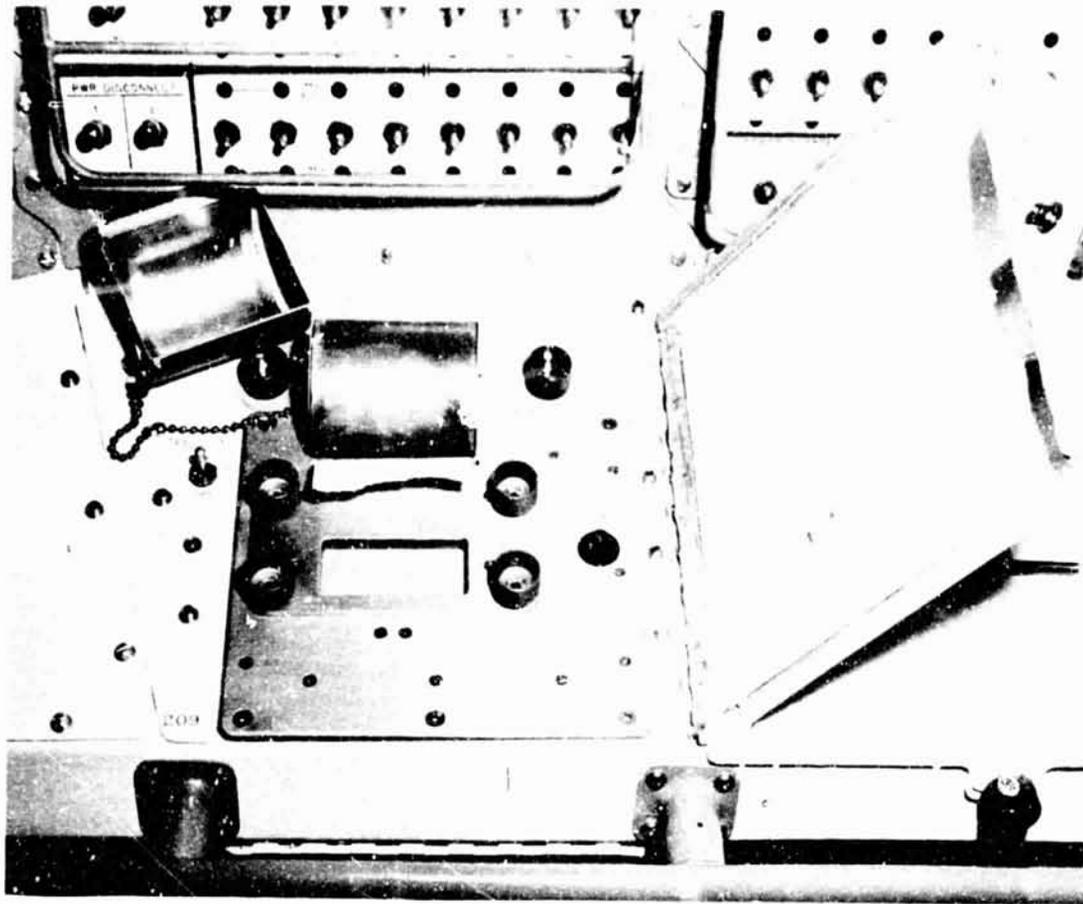
The laboratory command system provided commands to the acquisition and docking lights, the VHF rendezvous and ranging system, the dishcone antenna deployment, the laboratory data system, the environmental control systems, the laboratory power system, and several experiments. The system also provided backup commands to operate the solar observatory data and command systems.

Teleprinter.- The teleprinter provides the crew with hard copy instructions and messages from mission control. The teleprinter is the first hard-copy communication system used in space. Printing is done by thermal contact on standard thermal coated printer paper. The teleprinter is driven by commands issued from Mission Control through the laboratory digital command system. Each transmitted teleprinter command contains 24 bits. Three bits address the vehicle, the next three address the teleprinter, and the remaining bits are the data word. Each teleprinter character requires six data bits; therefore, three characters are printed for each command. Ten commands are processed to provide 1 line (30 characters) on the teleprinter. An address interrogate signal enables the interface unit and the teleprinter subsystem when data are to be printed for the crew. Figure 5-9 shows the teleprinter installation paper cartridge and a test printout.

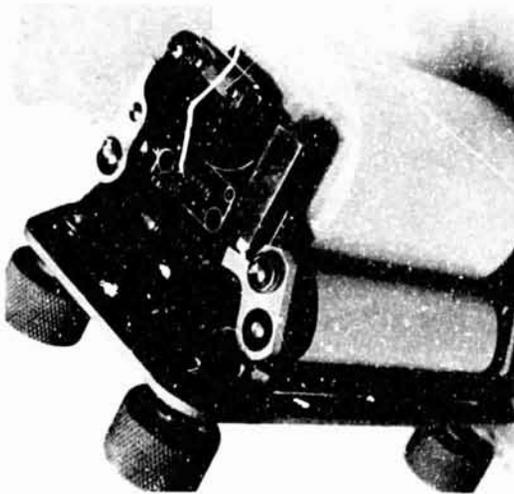
The teleprinter was activated on Day 13, after the first crew arrived, operated successfully throughout the mission. The crew reported on the first day that the printing at the end of the first message and on succeeding messages for that day was faint. A low temperature test performed on a test unit on the ground indicated that the faint printing was due to low temperatures at the teleprinter's location. After the surroundings warmed up, the printing was dark enough. The teleprinter system was reactivated by the second crew on Day 76. Its operation was normal until Day 86, when the paper drive mechanism on the teleprinter failed. The unit was replaced by the onboard spare, which performed satisfactorily during the remainder of the mission. One problem with the printer seemed to occur intermittently with the normal replacement of paper cartridges. Sometimes after a replacement the crew would report light printing, but normally the print quality was good. The cause of this recurring problem was evidently related to use and maintenance. After the crew cleared the teleprinter print head with cotton swabs and alcohol on Day 256, the problem cleared up and did not recur. More than 300 messages were sent to the crews during the mission, requiring about 30 rolls, or 3600 feet, of teleprinter paper.

### 5.2.2 Solar Observatory Digital Command System

The system consists of dual dipole command antennas, receivers, and decoders. Figure 5-10 is a diagram of this command system. The components are arranged to provide two independent, parallel signal paths. The two paths are redundant, since only one signal path is required for implementing the uplink commands. The ground stations can address either, or both, of the systems.



(a) Installation with acoustic cover open



(b) Paper cartridge

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A B C D E F G H I J K L M N O
P Q R S T U V W X Y Z
1 2 3 4 5 6 7 8 9 0
. ' & # * $ % ! ? / / . + - =
. . . ' < > ( ) _ -
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THIS MESSAGE PRINTED AT AM-
BIENT TEMP WITH TELEPRINTER
INSTALLED IN STU RACK, ON THE
MORNING AFTER TEMP TESTS.
09:20
-----

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(c) Sample message

Figure 5-9.- Teleprinter

A command can be either a switch selector command or a digital computer command and is coded such that it will perform only one unique function. Command data are placed in computer storage at the various ground stations for subsequent transmission. The uplink command is received by the two halfwavelength dipole antennas. One is mounted at the end of and within the plane of solar array wing 1;

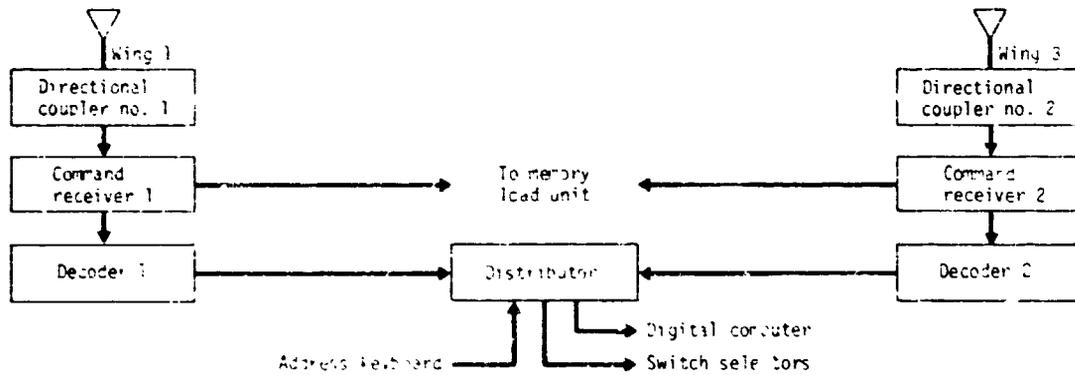


Figure 5-10.- Solar observatory command system.

the other is mounted on solar array wing 3 perpendicular to the plane of the wings. This geometry gives a quadrature relationship between the two antenna patterns. The dipoles exhibit predominantly linear polarization, omnidirectional coverage, and a 20-megahertz bandwidth.

The decoder sends commands to four switch selectors and updates information to the computers. The switch selectors provide commands to the power system canister thermal system, data system, attitude control system, solar experiments, and television system. The switch selectors and the computers may also be addressed by the crew from the digital address system keyboard on the control and display panel. The use of the keyboard automatically inhibits the ground command system. The ground command can also be inhibited totally or in part by switches on the control panel.

The digital command system was activated on Day 1 and remained in continuous operation for approximately 6546 hours without error or problems during the Skylab mission. On typical manned days such as Days 19 and 225 the system processed approximately 275 commands. On unmanned days such as Day 10 approximately 150 commands were processed. Approximately 59,650 commands were executed during the Skylab mission.

Because of the launch anomalies and the resulting high temperature problems, the command system was used much more than anticipated during the early days of the mission, but no problems were encountered. Both primary and secondary digital command systems were operating normally, with no indications of degradation, at the end of the mission. Table 5-X is a summary of the commands.

### 5.3 AUDIO SYSTEM

The audio system supports voice communications for crewmen both within Skylab and while they are engaged in extravehicular activities. It also provides a real-time two-way communication link between ground stations and the crewman. Voice recording capability is also provided on the data recorder. In addition, the system supports the gathering of biomedical data and operation of the caution and warning system and provides audio to the video tape recorder. Figure 5-11 is a functional diagram of the system which consists of the following: 13 speaker intercom assemblies, 2 extravehicular activity panels, 1 intravehicular activity

Table 5-X.- Solar Observatory Command Summary

System controlled	Number of commands per system	
Thermal	19	* The computer has a capability of 16,384 16-bit words in the memory. All memory locations can be addressed through the command receiver-decoder.
Electrical power	93	
Attitude control	119	
Telemetry	103	
Extravehicular activities	5	
Television	8	
Environmental and thermal	4	
Experiments	96	
Zero test	4	
Register test	4	
Computer commands*	40	
Total	495	

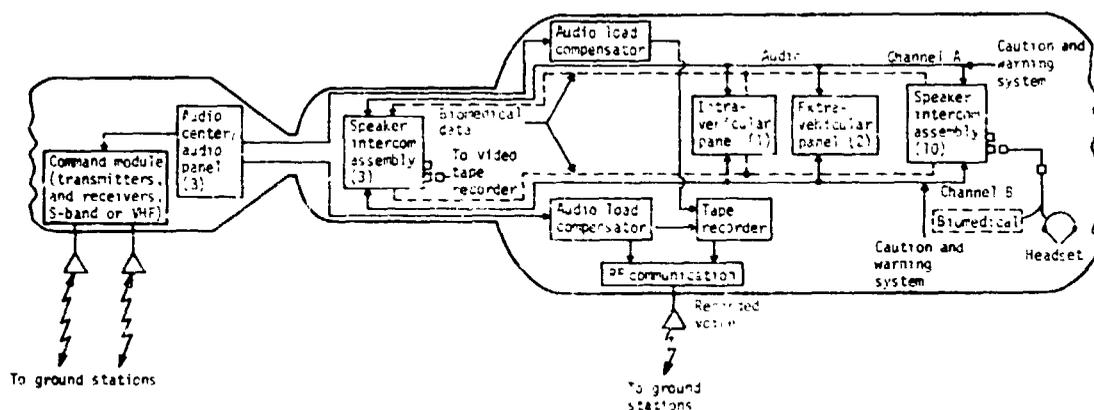


Figure 5-11.- Audio system.

panel, 2 audio load compensators, 3 command module audio centers, and a command module speaker box. Figure 5-12 shows a typical intercom installation.

Two independent channels, A and B, provide redundant voice communication capability throughout the Skylab. Voice from any input unit can be routed through either channel. Each channel has a separate audio load compensator which receives a microphone signal from an input and routes it to the command module audio center associated with the selected channel. The audio system can be operated using either the speaker intercom assemblies or headsets. The real-time voice is transmitted to the ground sites through the command and service module. Recorded voice is transmitted through the laboratory data system.

A channel selector switch on the intercom panel allows selection of the "ON" and "SLEEP" mode for either channel. The channel selector switch in the "ON" mode links the intercom to an audio load compensator. The selector switch in the "SLEEP" mode disables the speaker output of the intercom except when a "CALL" signal or ground-commanded crew alert is received. The intercom call switch must be manually maintained in the push-to-talk position. The call switch enables the intercom loop on both channels by supplying the microphone signal to both audio load compensators simultaneously. The laboratory has 13 intercoms, some of which directly face

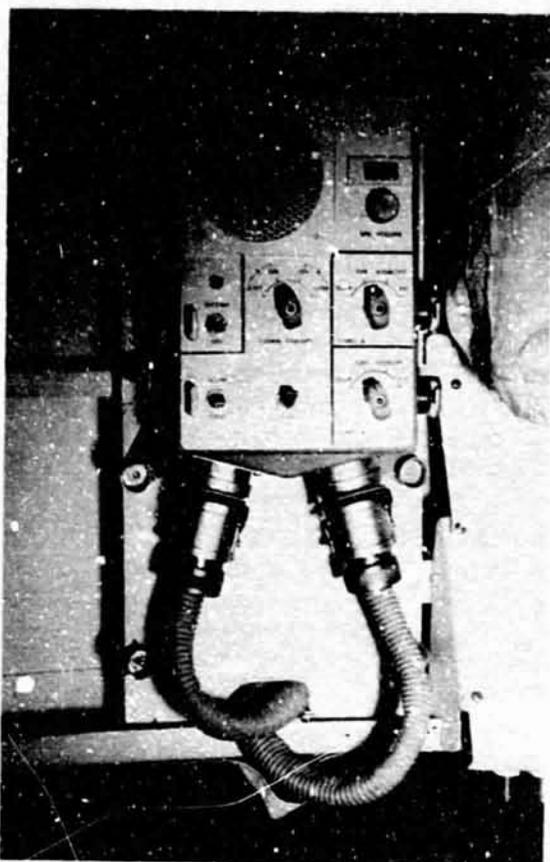


Figure 5-12.- Intercom - typical installation.

each other. Three of these intercoms are located in the docking adapter in close proximity to each other to support certain Earth observations experiments. Feedback had occurred during the airlock-docking adapter ground test; however, it was believed the problem could be handled by operating procedures. Feedback was also noted during the ground system test, but it was suppressed by decreasing the volume control of the activated speakers.

The audio system was activated by the first crew on Day 13. During this period, when certain combinations of intercoms were turned on and the microphone was activated in one of them, feedback occurred because of the high volume control setting on the second intercom. This required a crewman to turn the volume control down on the second intercom. The interaction was more pronounced when the microphone was keyed with no voice, which put the amplifiers in the command module audio center in a high gain condition. Otherwise, voice quality and levels were satisfactory for both the intercoms and the headsets. One intercom in the wardroom was used most often. Three other intercoms were within the acoustical field of the one used most often. The probability was high that feedback would occur with any two of these intercoms powered up,

the volume control on one turned up, and the microphone circuit on the other intercom activated. There was no feedback from the intercom in the waste management compartment and those in the sleeping compartment because of the acoustical isolation provided by the lockers and the walls. There was no feedback between the intercoms in the docking adapter and those in the workshop.

During a television tour of the Skylab, voice recording using the lightweight headset on the video tape recorder was at times fading and unintelligible. This was not because of equipment malfunction, but because the headset was used as a hand-held microphone. The microphone in question must be in close proximity (0.5 inch or less) to the lips. Voice communication during extravehicular activity was satisfactory, with good quality communication obtained between the crew and mission controllers. Background noise due to suit gas flow was minimal and did not degrade voice intelligibility.

A review of tape recorded voice indicated that the voice quality was satisfactory and there was no detectable crosstalk from the other recorded channel. No equipment problems were noted in operating the recorder from any of the intercoms or panel-mounted controls. During the first manned period the crew indicated the call switch was never used, although the switch was checked once to determine its operation. No problems were encountered with connecting and disconnecting the umbilical connectors to the intercoms. The second crew activated the audio system on Day 76. The audio feedback problem encountered by the first

crew was still an annoyance during the second manned period. Less feedback occurred during real-time voice transmission, however, because of improved intercom configuration control.

The channel A audio system was used exclusively to provide real-time air-to-ground communications, onboard communications, and recorded voice transmissions through Day 79. The quality of crew voice transmissions was satisfactory throughout this period. On Day 79 the channel B audio circuit was activated to make recording on the laboratory recorders possible. After this activation, voice reception from tape playbacks was unintelligible at the ground stations. The crew successfully initiated a number of voice tape playbacks on Day 80 using Channel A, indicating the tape recorder was not the source of the problem. The audio system was reconfigured to provide real-time air-to-ground communications, on-board communications on the channel B audio circuit, and recorded (delayed-time voice) communications on the channel A audio circuit, and it remained in this configuration for the remainder of the second manned period. The crew conducted a troubleshooting procedure on the channel B audio circuit on Day 88 which indicated that the recorded voice problem was due to degraded operation of the tape recorder amplifier and associated power supply portion of the audio load compensator.

Noise oscillations at 4 hertz were heard on the intercom loop (channel B) on Day 132, accompanied by a drop in the earphone level. However, communication could be maintained in spite of this problem, which lasted no more than 1 day. The channel B audio load compensator was identified as a possible cause. Following deactivation of the audio system on Day 135, this same problem occurred in the command module audio system after undocking. Because of this occurrence, the noise problem was attributed to the command module components of the system.

Because of the loss of one of the tape recorder amplifiers, a contingency voice tape recorder adapter cable was developed as a means of voice recording should the one existing channel A fail. A modification kit was also developed for providing an additional load on the Saturn Workshop command module microphone lines to reduce the input level to the command module audio center and to load the earphone lines when transmitting from the Saturn Workshop to the ground.

The recorder cable and kit were carried up by the third crew. The audio system was reactivated on Day 188, and the antifeedback modification was installed in the command module on Day 195. On Day 200, an intercom unit in the docking adapter lost its microphone amplifier and was replaced with a spare unit. On Days 251 and 253, audio channel B again experienced noise and low volume. While the noise problems on Days 132 and 251 lasted approximately 1 day, the noise occurrence beginning on Day 253 lasted throughout the mission.

Although the first occurrence was concluded to be isolated to the command module (since this noise was also heard during the reentry) it is probable that all three noise occurrences and low volume were due to intermittent component degradation in the channel B audio load compensator earphone amplifier, which finally failed on Day 254.

The intercoms were heavily used during the mission primarily because they did not encumber the crew's mobility in the large volume provided. Headsets and umbilicals were used for extravehicular activities and voice annotation. Combining the internal communication, air-to-ground transmission, voice annotation, and biomedical, caution and warning, and headset interfaces within one intercom

unit required the use of a large number (13) of these units. These varied requirements resulted in nine intercoms in the lower half of the workshop, requiring considerable crew discipline to prevent feedback. The installation of the antifeedback network assembly, which reduced the system gain, proved to be very effective during the third manned period.

Although two failures occurred in the audio load compensator, its redundant design enabled it to maintain a two-channel operation as well as voice record capability. However, the loss of the channel B tape recorder amplifier and the necessity of opening a circuit breaker to disable a noisy earphone amplifier and of closing it when recording was a major problem. Fortunately this occurred late in the third manned period. The system provided the required voice communication throughout the mission. In particular, the backup and redundancy provisions were a prime factor in maintaining the system at its full capability. Table 5-XI lists significant events for the audio system.

Table 5-XI.- Saturn Workshop Audio System Events

Day	Manned period	System operation
13	First	Audio system activation. Audio feedback occurred periodically during mission.
40	First	Audio system deactivated.
76	Second	Audio system reactivated.
79	Second	Garbled voice from laboratory tape playbacks (recorder amplifier failure in Channel B). Only one recorder amplifier available for rest of mission. Channel A and Channel B configuration reversed, i.e., Channel A - Voice recording Channel B - Intercom and communication with ground.
96	Second	Broken switch on intercom (replaced).
97	Second	Hand-held microphone noisy - stowed, and not used.
132	Second	Noise oscillation at 4 hertz heard on Channel B, associated with loss of system gain. Problem disappeared same day and system returned to normal.
135	Second	Audio system deactivated.
188	Third	Audio system reactivated.
195	Third	Antifeedback communication network installed.
200	Third	Intercom failure in docking adapter. (replaced by on-board spare).
251 and 253	Third	Channel B earphone amplifier noise.
254	Third	Channel B audio load compensator earphone amplifier failure.
270	Third	Audio system deactivated.

#### 5.4 TELEVISION SYSTEM

The Skylab television system has two video networks for separate purposes. The laboratory network provides views of the crew's activities, hardware, panels, and other items requested by the ground observers. Press conferences and views of weather phenomena and other Earth features are also transmitted to the ground stations. The solar observatory video network provides solar experiment pointing and adjustment and scientific data. The ground tracking sites used for television are mainly the continental United States stations of Goldstone, Texas, and Merritt Island. These stations are connected by video lines to Johnson Space Center. Figure 5-13 is a diagram of the television system.

##### 5.4.1 Laboratory Television

The laboratory system includes two portable color cameras and six television input stations located throughout the Skylab so that the crew can program

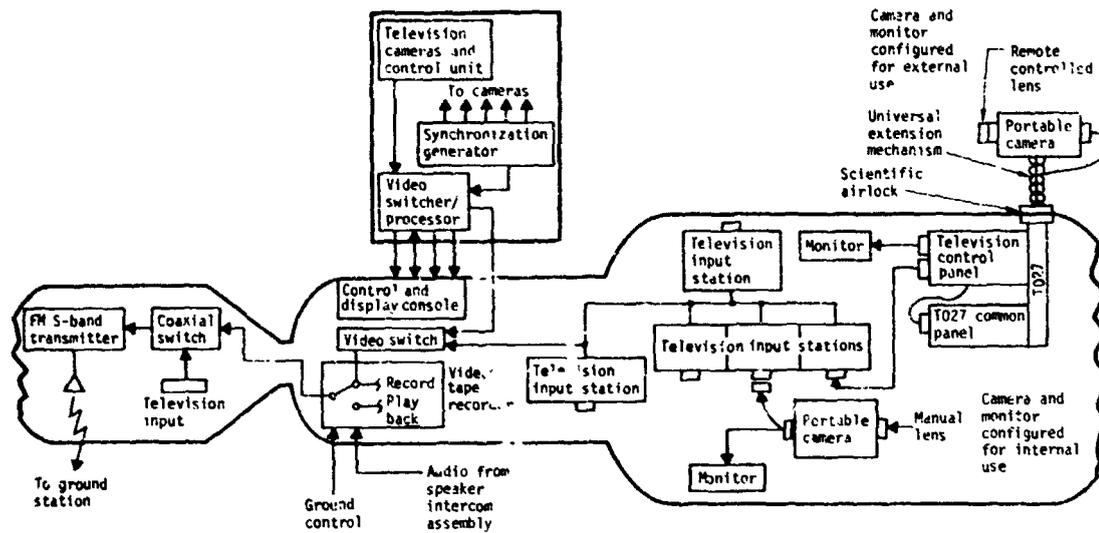


Figure 5-13.- television system.

television scenes of selected activities. Exterior scenes can be viewed by looking out windows, by taking a camera out the airlock hatch, by extending the camera on a boom from the scientific airlock in the workshop, or by use of an adapter with an experiment viewfinder tracking system. The system also allows the television signal from any one of the five solar observatory cameras to be selected for transmission or recording.

A video tape recorder controlled by the crew can record up to 30 minutes of video information. Playback is controlled from the ground and requires the same time span used for recording. During recorder playback to the ground stations, live television coverage is not available.

The laboratory television performed as predicted with few significant problems. Selected video recordings were analyzed to evaluate the color and voice quality. The color converter was set up using standard color bar signals that had been prerecorded at the beginning and end of each scene. This gave the conversion system a standard setup with no compensation for the camera color wheel filters or the nonstandard color temperature of the lighting aboard Skylab. Under these conditions all scenes have a yellowish to greenish tint to them, particularly with camera No. 3005. Scenes taken with camera No. 3002 were not as prominently off color, and at times flesh tones of the crew were almost a normal suntan color. All scenes exhibited a lack of color saturation.

The color differences between scenes were caused by lighting conditions as a crewman moved around. This was most apparent in scenes of the airlock extravehicular activities. All of these effects, however, were compensated in the color converter and television processing. This required individual manual setup of scenes with different illumination to obtain the best apparent picture quality; however, it was well within the processing capabilities. The normally converted and compensated pictures released to the commercial networks are of good quality. The compensation worked well; lack of color saturation in the video was not a system constraint. Figure 5-14 shows a crewman using the television camera to photograph an experiment.

- |                               |                                |
|-------------------------------|--------------------------------|
| A. Water tanks                | E. Spider experiment enclosure |
| B. General illumination light | F. Portable color TV camera    |
| C. Universal mount            | G. TV monitor                  |
| D. High intensity light       | H. Intercom headset            |

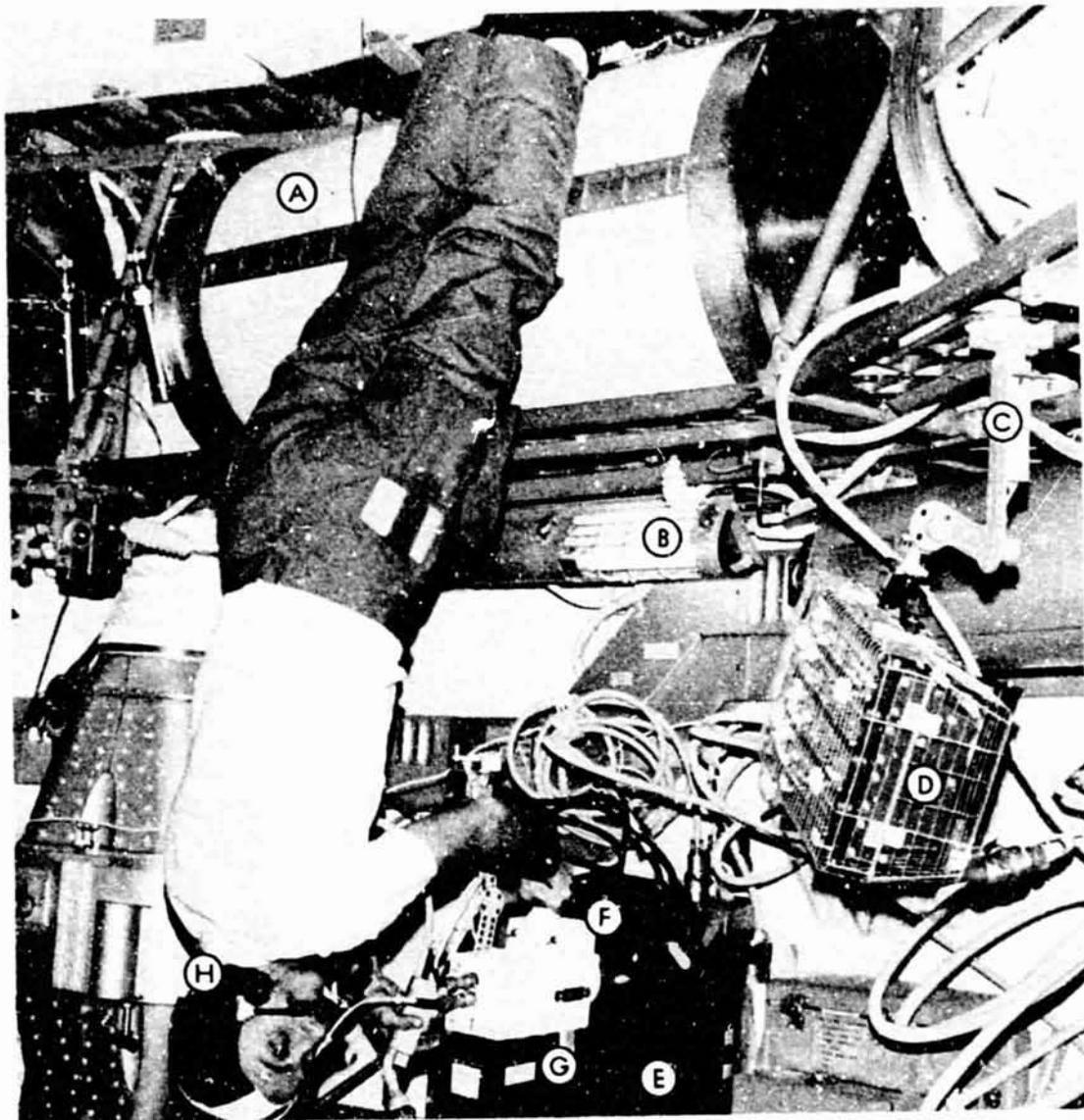


Figure 5-14.- Crewman using television camera to photograph spider activity.

On Day 20, portable color camera No. 3005 lost its output. The failure was caused by contamination particles in a hybrid microcircuit in the synchronizing generator-vertical interval test signal adder section of the camera. The contamination caused a complete failure of synchronization and drive signals within the camera, leading to a total output failure of video. This was not considered a camera design deficiency. The crew substituted camera No. 3002, which functioned throughout the remainder of the mission.

During the first manned period, color camera No. 3002 exhibited a number of black spots or dots in the picture which became more numerous as the mission progressed. The spots were not always readily apparent and were affected by the

through the viewfinder tracking system. In this scene the spots were well focused, and estimates of the number of spots range from 25 to 50. An examination of the camera after the end of the first manned period disclosed that the spots were small contamination particles on the face of the vidicon. These spots were extremely small, probably less than 0.025 millimeter in diameter, but the magnification of the television system made them very noticeable on the monitor.

The sound from the video tape recorder was very intelligible and of good communication quality. When the lightweight headset was hand held, the level varied greatly because of the direction and distance of the microphone in relation to the sound sources.

The second crew carried up another portable color camera, No. 3006, to replace the failed unit. On Day 76, the first day of the second manned period, this television camera's color wheel failed to rotate. The wheel stuck in such a position as to shadow the upper half of the picture. However, the lower half was good monochrome video and was aired by several networks. Several days later, the crew removed the camera lens and spun the color wheel manually. This action evidently freed the wheel, since it operated normally during the remainder of the mission.

On Day 81, the video tape recorder failed during playback. The ground stations reported no modulation on the transmitter carrier. Onboard troubleshooting was unsuccessful, so the crew replaced the malfunctioning recorder with the spare recorder. The crew removed several printed circuit boards from the recorder and returned them for examination. A video limiter-demodulator board was found to be defective. Replacement printed circuit boards were tested and carried up by the third crew. The replacement recorder on the vehicle performed properly for the remainder of the mission, so the spare printed circuit boards were never used.

On Day 90, during a video tape playback, the audio was garbled. Investigation showed that the problem was caused by a faulty hand-held microphone. The microphone was removed from service and the problem never recurred.

During an extravehicular activity on Day 103, a crewman carried portable camera No. 3002 outside the vehicle. Thermal analysis had predicted a maximum camera temperature of 125°F. However, when the temperature climbed above the operating limit of 129°F and approached 158°F, the camera was turned off and allowed to cool. When the camera was reactivated, no output was received. Failure was attributed to the high temperature experienced by the camera. The other television camera was used for the remainder of the second manned period.

On Day 123, one of the television camera power cables and one of the television monitor cables were found to have intermittent circuits when flexed. These were replaced by the cables for the other camera and normal performance was restored.

Another portable color camera, No. 3004, and a pair of replacement cables were brought up with the third crew. During the third manned period, on Day 229, the crew reported that while attempting to connect the camera cable to the television input station, a broken pin floated out of the connector on the input station. The connector on the cable was inspected and was determined to be undamaged. A spare input station was installed by the crew in place of the defective unit. Operation from this station, as well as all the others, was normal for the remainder of the mission.

#### 5.4.2 Solar Observatory Television

The solar observatory video network comprises five television cameras and associated electronics. The outputs of these cameras are monitored by the crew from displays on a console in the docking adapter. Synchronizing generators provide drive signals to the cameras and the console monitors. Two video switcher-processors add synchronizing signals to the video outputs and condition them for video recording or transmission to the ground stations.

Approximately one-third of the television downlink time was devoted to solar observatory television. The hydrogen alpha telescope, white light coronagraph, and extreme ultraviolet monitor sequences gave very good views of the Sun, which gave the Principal Investigators a preview of the data to be expected. On Day 23, while the doors of the white light coronagraph camera were being closed to give a test pattern, a sudden light overload to the vidicon occurred. This was caused by sunlight being reflected from somewhere within the telescope canister, then off the doors, which were moving to the closed door position, and into the camera. No damage to the camera could be detected after this occurrence. A 250-ampere current spike occurred on the solar observatory bus 2 on Day 83, and a short time later the voltage went to zero. Investigation showed that a short had occurred. All equipment was removed from bus 2 and transferred to bus 1. The television equipment operated normally for a period of time. Monitor 1 failed on Day 132. It was replaced during the third manned period (5.8.6). This monitor had experienced transient overstresses internally during the bus failure.

On occasion, the crew observed a slowly oscillating blooming of the image from the hydrogen alpha 2 camera. A particular change in light conditions at certain zoom lens settings caused oscillations in the automatic gain control circuitry of the television camera. This condition was readily corrected by zooming toward the 5X position until the oscillation stopped and then zooming back to the desired position. Because of the length of the second and third manned periods, a much greater volume of data was accumulated than expected. A review of the ground station video recordings showed that the overall quality of the television pictures was generally the same as experienced during the first manned period and remained constant throughout the mission.

#### 5.5 CAUTION AND WARNING SYSTEM

The caution and warning system monitors the performance of the Saturn Workshop systems and alerts the crew to hazards or out-of-tolerance conditions that could result in jeopardizing the crew or could compromise primary mission objectives. The caution and warning system consists of two isolated subsystems, the emergency subsystem and the caution and warning subsystem. Figure 5-15 is a diagram of the system. The emergency subsystem alerts the crew to a fire or rapid loss of pressure requiring immediate crew response. The caution and warning subsystem alerts the crew to system out-of-tolerance conditions that require crew response immediately (warning) or within a short time (caution).

The out-of-tolerance condition activates an audible tone and illuminates an indicator light identifying the out-of-tolerance parameter. The tones are coded according to the reaction time required of the crew. The emergency alarm has two different tones: a siren indicating a fire and a buzzer indicating a rapid cluster pressure loss. The tones are broadcast throughout the Skylab by two klaxon-type horns, one located in the workshop and one located in the airlock.

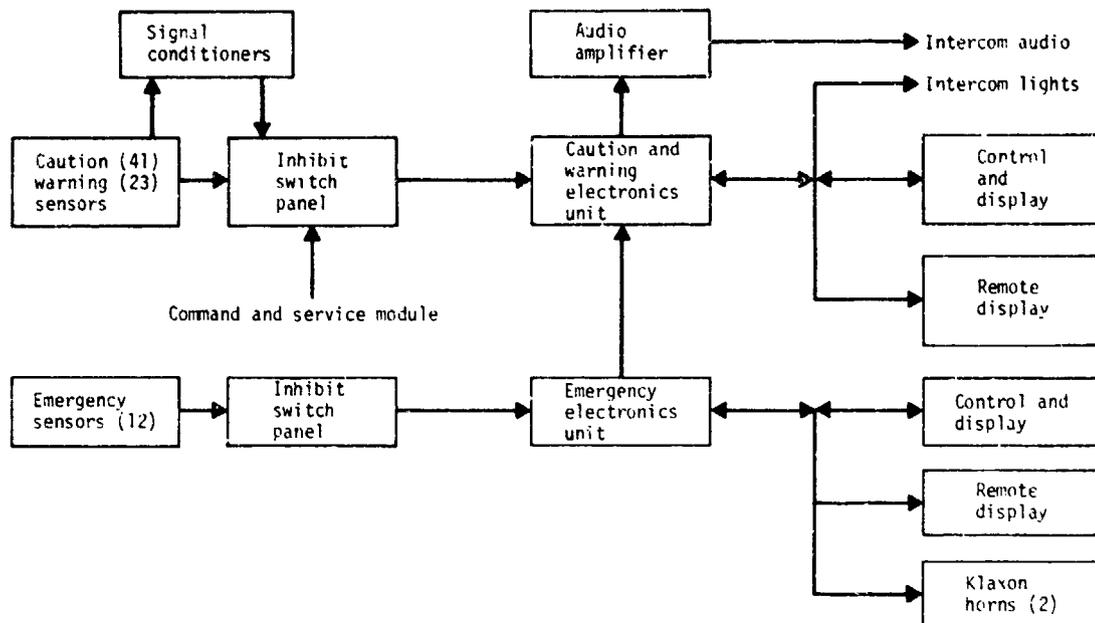


Figure 5-15.- Caution and warning system.

A warning alarm, requiring immediate crew response, has a modulated 1-kilohertz tone. A caution alarm, requiring crew response within a reasonable time, has a 1-kilohertz continuous tone. The caution and warning tones are broadcast throughout the Skylab by the speaker intercom assemblies. There are 40 indicator lights on the airlock panel which aid the crew in identifying the out-of-tolerance condition.

Emergency and warning indicator lights are color coded aviation red; caution indicator lights are colored aviation yellow. Selected measurement indicators are also illuminated on the workshop repeater panel.

The major power and control switches for the Saturn Workshop caution and warning system are located on a panel in the airlock. The master alarm indicator light switch, which is colored aviation red, is illuminated when either an emergency, warning, or caution parameter is activated. When depressed, the master alarm light switch provides a reset signal to the caution and warning unit electronics to terminate the audio tones and extinguish all master alarm light switches and master alarm status lights. The memory recall light switch has an amber lens and is used to recall the measurement which activated the subsystem. Depressing the memory recall light switch causes the identification lights to be illuminated for the measurement stored in memory. This provides after-the-fact identification of short term subsystem activations. A switch erases the memory circuitry in the unit and extinguishes the recall light switch. Three power switches are provided for controlling the caution and warning system. One switch is used to control power to the caution and warning subsystem, and the other two switches are used for the emergency subsystem. Four test switches--one each for fire, rapid pressure change, warning, and caution--are provided for testing the caution and warning subsystem electronics, audio tone, and visual displays. Three volume controls are also provided for controlling the audio levels of the emergency, warning, and caution tones.

The caution and warning system was activated on Day 13 and deactivated on Day 40 at the end of the first manned period. The system operated satisfactorily throughout this period and was triggered approximately 60 times. Control moment gyro saturation, attitude control malfunction of the rate gyros, coolant loop low flow and low temperature, carbon dioxide pressure, condensate tank pressure, low workshop bus voltage, and rapid cabin pressure change were a few of the out-of-tolerance conditions detected. Many of the alarms occurred because of system management and were either anticipated or explainable.

On Days 21 through 26 emergency subsystem 1 and rapid pressure change sensor 1 were powered down during crew wake periods because of limited power. During this time all fire sensors were powered from side 2 of the fire sensor control panel. Side 2 of the redundant caution and warning subunit was powered down during crew wake periods during this period. No detrimental effects were detected during the abnormal system operation.

There were six false alarms during the first manned period, all associated with the fire sensor assemblies. Three false alarms occurred on Day 13 shortly after caution and warning system activation. The alarms were attributed to excessively high wall temperatures (approximately 144°F in the workshop). The fire sensor assemblies are qualified for an operating temperature of 120°F.

Two more false fire alarms occurred during passes through the South Atlantic Anomaly, where the Earth's magnetic field dips inward, allowing high energy radiation to come closer to the Earth. The alarms occurred on Days 14 and 19. Both alarms were activated by the fire sensors located in the aft compartment workshop cooling module. According to dosimeter and proton spectrometer data, the alarms occurred during peak radiation levels. A statistical analysis of system characteristics, based on estimates of radiation levels expected to be encountered in the Skylab orbit, had indicated that a threshold of 35 counts per second and a time constant of 1 second would preclude more than 1 false alarm for each 56-day manned period. To compensate for the unexpected, however, the fire sensors were designed to allow selection of sensitivity settings from 25 to 75 counts per second in 10-count increments. The sensitivity of the activated fire sensor was reduced from 35 to 45 counts per second.

The crew reported a low laboratory bus voltage alarm on Day 20. Real-time troubleshooting revealed that the caution and warning workshop bus 1 and 2 sensing circuit breakers and a workshop power feeder circuit breaker were open. A system checkout procedure initiated on Day 22 revealed no system anomalies. The circuit breakers were closed and the low laboratory bus voltage alarm was re-activated. The system performed normally through completion of the mission.

A rapid pressure change alarm occurred three times during the first manned period. The first alarm occurred on Day 24 just before extravehicular activity. The crew had to perform a system reconfiguration. The slight pressure differential between compartments when the airlock to workshop hatch was opened activated the first alarm. The other two were expected alarms that occurred during airlock repressurization after extravehicular activities on Days 25 and 37.

During the first extravehicular activity on Day 25, a fire sensor located in the aft airlock compartment was activated by sunlight through the opened hatch, generating the sixth false alarm. The crew procedures were changed to

inhibit these fire sensors during extravehicular activity, since the aft airlock compartment is evacuated during this period. Also on Day 25, the crew reported that no pump-pressure-difference alarm was received when the suit umbilical system pump was activated before the extravehicular activity. Under normal system operation, an alarm would be generated during activation. The caution and warning pressure sensor may have been damaged when the suit umbilical system was exposed to extremely low temperature earlier that day. Activation and check-out of the suit umbilical system by the second crew verified that the pump pressure sensor had failed.

On Day 27, a fire system test was performed and a fire sensor failed to respond. On Day 28 a fire system failure isolation test was performed which indicated a failure of side 2 of the fire sensor panel. The fire sensor control panel was successfully replaced with an inflight spare. The removed panel was retained onboard as an inflight spare for two workshop locations which only use side 1. The fire sensor, as well as the control panel, was replaced during the isolation test. The removed sensor was marked "USED" and stowed onboard the vehicle.

The second crew activated the caution and warning system on Day 76 and deactivated it on Day 135. During extravehicular activities on Day 103, caution and warning subsystem 2 and emergency subsystem 2 were turned off for 6 hours to minimize system loading. The system performed satisfactorily during this minimum load configuration.

The system operated satisfactorily throughout the second manned period and generated in excess of 100 alarms. The parameters that generated the alarms were: Skylab attitude (thruster stuck on high rate); primary and secondary coolant flow; attitude control system malfunction (control moment gyro saturated, thruster control only); molecular sieve out, carbon dioxide pressure high; command and service module malfunction; fire; sieve gas flow; workshop gas interchange; condensate tank pressure change; caution and warning power; emergency power; extravehicular activity; and rapid pressure change. The majority of these alarms were due to excessive attitude change rates caused by experiment venting and system management and were explainable.

There were three false alarms generated during the second manned period. Of the false alarms, one was a warning and the remaining two were fire alarms. The false warning alarm occurred on Day 103, during the extravehicular activity in which the supplementary rate gyro package was installed. The crew attempted to identify the cause of the alarm, but the memory recall failed to indicate which parameter triggered the alarm. A lamp test was performed on Day 104, but no burned out indicator lights were found. A warning system test was initiated on Day 111 to check the memory recall capability of the warning parameters. No problems were found.

Both of the false fire alarms were attributed to high amounts of ultraviolet radiation entering the vehicle through windows which had their sunshades removed for picture taking. The first alarm, on Day 83, was initiated by a wardroom fire sensor assembly. The wardroom window was facing the Earth while the sunshade was removed. The second fire alarm occurred on Day 114. Performance of certain experiments required that the sunshade be removed from a scientific airlock window. The ultraviolet radiation which entered the vehicle activated two fire sensor assemblies.

During the second manned period, rapid pressure change alarms occurred four times. Two of these were expected alarms that occurred during airlock repressurization after extravehicular activities on Days 76 and 132. The crew caused two rapid pressure change alarms by accidentally interrupting emergency power when they tripped a circuit breaker on Day 117 and a power switch on Day 120.

The crew deactivated the caution and warning system on Day 135. During the second crew debriefing, the crew suggested inhibiting the following caution parameters: workshop gas interchange, sieve A and B gas flow, and sieve A and B outlet carbon dioxide pressure. When the gas flow is switched from one bed to the other, a small amount of unprocessed gas bypasses the beds, causing the carbon dioxide pressure sensor in the bed discharge outlet to trigger the alarm. At least nine sieve A gas flow alarms were generated because of the sporadic flow caused by bed cycling. Sieve A gas flow was inhibited on Day 123. On Day 90, during the second manned period, molecular sieve A carbon dioxide pressure triggered the system. This parameter was inhibited on Day 91 and remained so for the rest of the mission. The workshop gas interchange parameter was inhibited on Day 118 following at least two alarms and replacement of the airlock duct fan.

The third crew activated the caution and warning system on Day 188. Check-out and test was by procedure, with no problems. Out of the 40 alarms which occurred during this period, two false alarms were observed. Both of these were generated by fire sensors while traveling through the high radiation belts of the South Atlantic Anomaly on Days 232 and 252. These sensors had not been adjusted to the higher level of radiation that the others were set for during the first manned period after the radiation belt had caused alarms. As this was late in the mission, their sensitivity was not changed, and no further false fire alarms occurred. About half of the alarms were from the attitude control system and all were explainable. High attitude rate changes caused gyro saturation alarms during maneuvering for Earth observations and comet observations. High torques on the vehicle caused by the crew during extravehicular activity and by experiment venting also generated these alarms. Other alarms were generated by coolant loop flow sensors during the crew resupplying of the coolant fluid and subsequent testing of the system. Housekeeping tasks which required turning off fans and other equipment caused other alarms. Rapid pressure change alarms were caused by repressurization of the airlock after extravehicular activities, which also had happened during the previous manned period.

On Days 243 and 264, the caution and warning systems were turned off during Earth observation and experiment pointing maneuvers as a power conservation measure. On Day 261, to preclude alarms during the data-taking time, the eight laboratory battery low charge (70 percent discharged) sensors were disabled during an Earth observation pass.

On Day 268, the crew inhibited sensors on the solar observatory canister pump pressure, canister coolant temperature, and canister heater temperature to preclude alarms during ground testing of the systems. The caution and warning system was turned off on Day 271 in accordance with the final deactivation procedure.

The crews performed emergency subsystem testing periodically throughout the mission. These tests included emergency system verification, fire sensor verification, and rapid pressure change sensor verification. Tests were also performed on the caution and warning subsystem. These included checks on crew alert

capability, tests of annunciator panel lamps, and warning system verification tests. All of the tests were performed without incident.

During the Skylab mission, the caution and warning system in the flight backup unit and in the Skylab test unit were maintained in a mission support mode. The backup caution and warning system configuration was identical to that of the flight vehicle. Special tests and operational modes were performed as required to support the resolution of problems or suspected problems on the Saturn Workshop in flight. Data were plotted on all system-related parameters to monitor system performance and to observe parameter trends for out-of-tolerance or any erratic operation. The test and backup units were used to help solve problems occurring during the mission that involved fire sensor false alarms and bus 1 and 2 low voltage alarms.

The caution and warning subsystem's audible alarms are transmitted throughout the vehicle by the intercom assemblies. A high level audio amplifier powers the speakers. The caution and warning to speaker interface functioned as expected throughout the mission. The crews reported that the caution and warning tone levels were adequate. No inflight adjustments were required.

The caution and warning system performance met all mission requirements. The alarms generated were correlated with telemetry data and provided a good cross check of system status. All alarms were explainable and most were expected. Ground controllers studied each daily flight plan, housekeeping and troubleshooting procedure, and maneuvering and venting operation, and alerted the crew to pending alarm activations. Being able to recall the alarm source and to inhibit expected alarm sensors enabled the crew to perform the planned activities without unnecessary interruption.

No false alarms occurred as the result of abnormal caution and warning system behavior or component malfunctions. The system was operational during all manned phases of the mission and successfully monitored all 76 preselected parameters, relieving the crew to perform other assigned activities. The crew reported that the system performed in an outstanding manner and that they were well pleased with all caution and warning system and crew interfaces, such as system control and inhibit switches, audio alarms, indicator lights, parameter categories, memory recall, and system reset capabilities. Out of the 76 parameters monitored, only the gas flow, the carbon dioxide sensor, and the control moment gyro saturated signals activated the system an excessive number of times. The control moment gyro saturation alarm was activated frequently during periods of high activity and because of rate gyro failures, while the carbon dioxide level and gas flow alarms resulted from the marginal sensing techniques used.

## 5.6 TIMING

The Saturn Workshop uses two independent time reference systems for its operations. The laboratory time reference is provided by precision electronic timers and associated hardware. The solar observatory computer generates mission time and distributes it in the required form by means of software programming.

### 5.6.1 Laboratory Time Reference System

The laboratory time reference system provides onboard time displays, generates time correlation for the instrumentation system and Earth observation

experiments, initiates time-dependent switchover to redundant components within the digital command system, and initiates other time-dependent equipment control.

The system consists of two electronic timers, two time correlation buffers, two digital display units, and an event timer. Figure 5-16 is a diagram of the time subsystem.

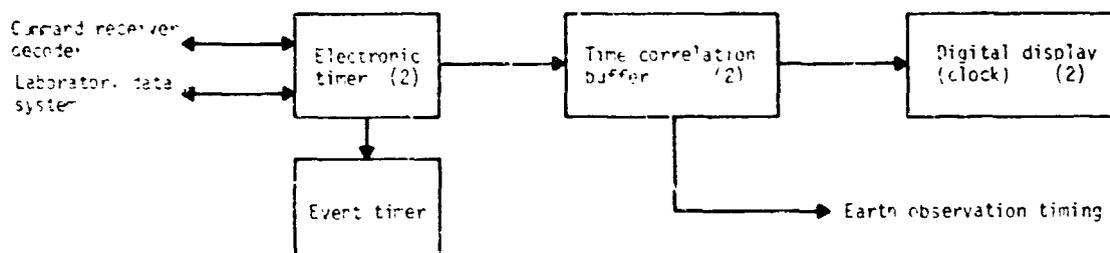


Figure 5-16.- Laboratory time reference system.

Each electronic timer has three magnetic shift registers. One register counts up in 0.25-second increments; the other two count down by the same amount. The count-up register data are converted in the time buffer to binary coded decimal signals which drive the clocks. These clocks display time synchronized to Greenwich mean time. The displays have a maximum display capability of 399 days 23 hours 59 minutes 59 seconds. A periodic reset of the count-up register sets the hours, minutes, and seconds displays to zero, synchronizing the two clocks. This reset is enabled by digital command issued by the ground station, and occurs at Gmt midnight. The countdown registers are used to generate signals which reset selected relays in the digital command system, allowing equipment to be turned off when the Saturn Workshop loses station contact. The event timer displays time at any selected rate up to a maximum of 999 hours 59 minutes 59 seconds. The event timer is manually controlled.

The primary electronic timer operated continuously after launch. The elapsed time drift error associated with this timer averaged less than 0.25 sec/day. This error rate is considerably better than the timer specification of 3 sec/day. All time register updates were successfully accomplished. During unmanned periods, while the secondary digital command system was powered down, the time-to-transfer register was kept updated to approximately 3 hours. While the crew was onboard, automatic switchover of the command system was not required, and the time-to-transfer register was updated to approximately 16 days. The count-up time register was reset to zero at Gmt midnight approximately seven times during the first manned period to maintain a drift error of less than 1 second. The time correlation buffer, event timer, and digital display units operated with no known discrepancies.

During the second unmanned and manned periods the time system operated normally, using the primary electronic timer, until Day 104. On that day, the secondary electronic timer was activated following a crew report that both digital display units were counting erratically. Timing inputs to other systems from the primary electronic timer were observed to be normal. The erratic display readouts occurred following the installation of the supplementary rate gyro package and were considered to be noise related. Before secondary timer activation, the primary timer had operated continuously for approximately 2478 hours.

After approximately 584 hours of operation, the secondary electronic timer elapsed time data also became erratic on Day 129. This failure consisted of minus 2 hours 16 minutes ( $\pm 1$  minute) time jumps observed on both data and displays. Only the elapsed time register output was observed to be erratic. The primary electronic timer was reactivated and operated satisfactorily. The secondary electronic timer was reactivated on Day 133 to determine what backup capability was remaining. The unit successfully provided 25 hours 3 minutes 33 seconds of elapsed time display; 23 hours 15 minutes 42 seconds of this total time occurred after an elapsed time reset to zero at Gmt midnight on Day 134. On Day 134 the primary electronic timer was again reactivated and operated satisfactorily for the remainder of the mission. The elapsed time error for the primary timer averaged approximately 0.25 sec/day too fast while the secondary timer error averaged approximately 0.4 sec/day too slow. The error from both timers is considerably better than the error specification of  $0 \pm 0.875$  sec/day.

### 5.6.2 Solar Observatory Time Reference System

The solar observatory computer is programed to provide navigation and timing information for the Saturn Workshop. The navigation program maintains knowledge of Saturn Workshop position in orbit relative to orbital midnight. Significant orbital event times are calculated and are used, along with position in orbit, to determine the day-night phase of orbit and the time remaining in the prevailing orbital phase. This information, along with several intermediate parameter calculations, is used to support other functional areas of the program such as maneuvering, momentum management, orbital plane error, and roll reference, as well as for display purposes and experiment timing. Mission time for display is maintained from one of two available mission timers. The redundant mission timers are 29-bit registers that store time in terms of days, hours, minutes, and seconds. These timers use basic oscillators separate from those used to provide computer software timing. Either timer may be selected and timer drift corrected by digital command from the ground station. Figure 5-17 shows the solar observatory timing interfaces.

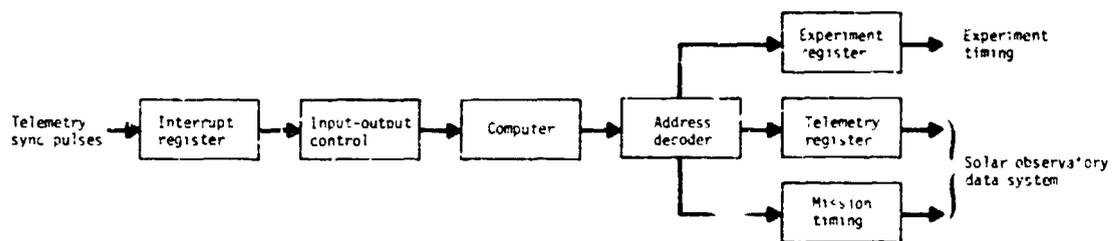


Figure 5-17.- Solar observatory time reference system.

The telemetry system provides two synchronization signals to the computer to provide time correlation with the computer and experiments. The transmitter provides 1-pulse-per-second and 24-pulses-per-second interrupt signals to the computer. The 1-pulse-per-second interrupt causes the computer to load the experiment register with mission timing, which is then transferred to the experiments once each second to be film recorded. The 24-per-second interrupt pulse causes the computer to generate a 50-bit word, which gives computer status, and to transfer the word to the telemetry register. Immediately after a 24-pulses-per-second telemetry signal is transmitted to the computer, the contents of the 50-bit telemetry interface register are sampled by the telemetry system and

transmitted to ground stations. The telemetry system also samples and transmits the current clock time with alternating 50-bit telemetry words. A backup 1-pulse-per-second signal is also generated by the computer from the 24 pulses per second to allow experiment timing in case the 1-pulse-per-second signal from the telemetry system should fail.

During the first 26 days of the Skylab mission, the two timers were used alternately in an effort to determine which timer was most stable. The first timer update occurred on Day 11 when timer B was updated by -11 seconds. On Day 21 timer A was updated by -4 seconds. On Day 24 timer B was updated for the last time by -18 seconds. After the switchover to the secondary computer, on Day 27, timer A was used for the remainder of the mission. During this time, timer A exhibited a positive drift of approximately 0.3 sec/day which was well within the specification tolerance. Following switchover, the timer was held within an accuracy of 3 seconds, requiring an update every 11 to 13 days. This resulted in a total of 21 updates to the secondary computer timer A.

The computer timing-telemetry interface satisfied all mission requirements with no known problems. However, some of the experiment data could have been analyzed to a greater depth had the computer and the telemetry timing been more closely synchronized. Had computer time been a multiple of telemetry time, synchronization would have been improved.

#### 5.7 RENDEZVOUS, RANGING, AND DOCKING AIDS

Two methods are used for rendezvous, ranging, and docking with the Saturn Workshop. Electronic devices provide radio location and ranging information. Figure 5-18 shows the VHF rendezvous and ranging system. Visual aids also provide location information, plus attitude alignment for the final phase of rendezvous maneuvering. High intensity tracking lights, colored docking lights, docking targets, and optical sights compose the visual aids. Figure 5-19 shows the visual tracking and docking aids.

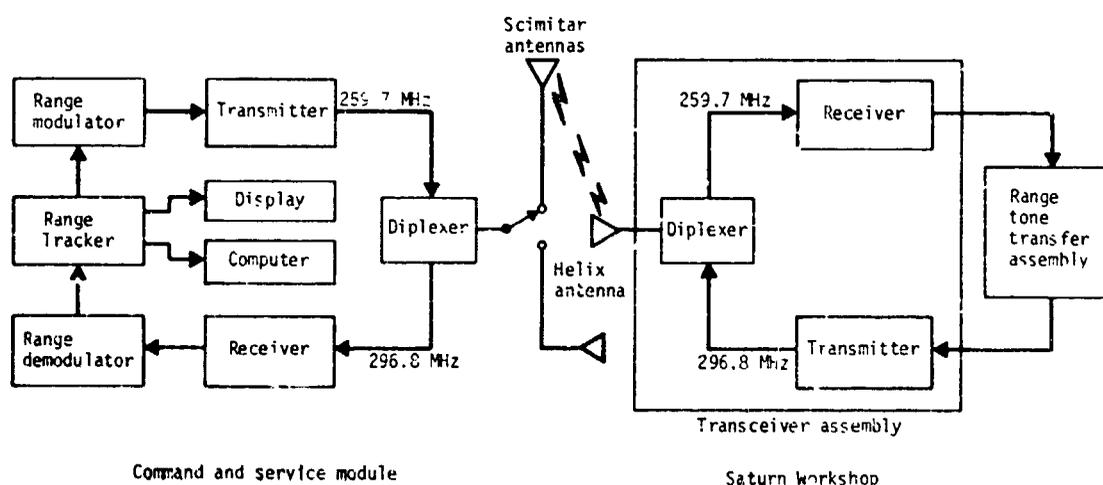


Figure 5-18.- Rendezvous and ranging system.

The VHF rendezvous and ranging system determines the closing distance and rate between the command and service module and the Saturn Workshop. During rendezvous the command module transmits a tone-modulated signal. A transponder onboard the Saturn Workshop receives and retransmits the signal. Command module

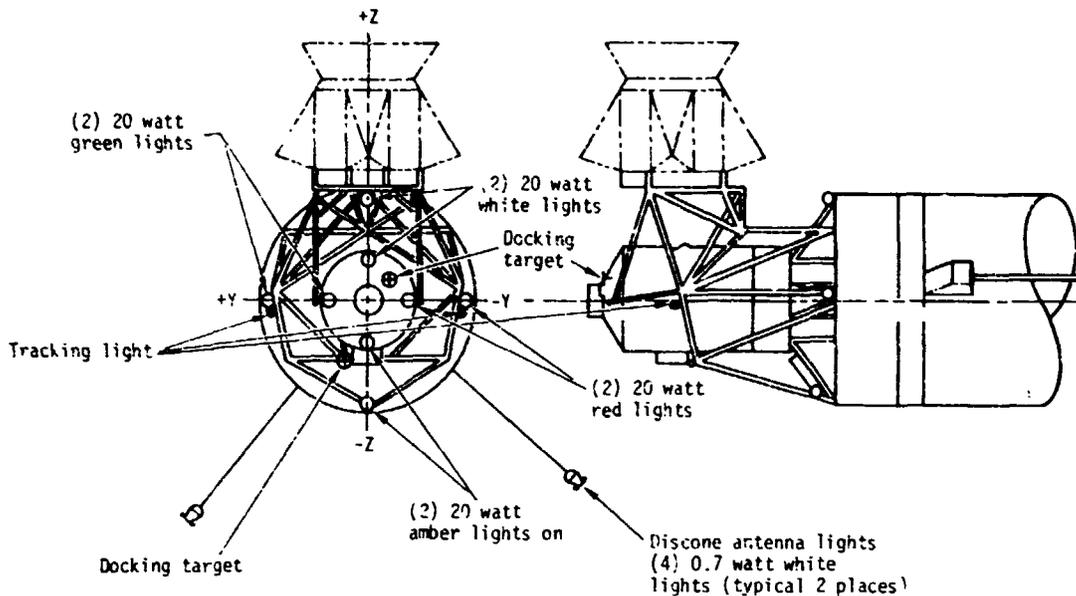


Figure 5-19.- Tracking and docking aids.

computers measure the phase differences of these signals and display the distance between the two spacecraft in increments of 0.1 nmi. Maximum distance for VHF ranging lockup is approximately 300 nmi.

The VHF ranging system operated twice during the first crew rendezvous for 3 hours and 2 hours, respectively. During rendezvous, the Saturn Workshop was in a 50-degree pitch-up attitude for thermal control. The 135 nmi acquisition range reported by the crew is considered very satisfactory considering that the antennas were not properly aligned. The system operated for 4.5 hours during the second crew rendezvous on Day 76. Initial acquisition occurred at a range of 390 nmi. This rendezvous was conducted with the Saturn Workshop in a solar inertial attitude to maintain full power capability. This profile was altered from the premission plan in which the Saturn Workshop was to be in a Z-axis local vertical attitude during much of the time the rendezvous systems were to be active. The solar inertial attitude caused some abnormal look angles, resulting in predictable periods of loss of contact between the command and service module and the Saturn Workshop. The third rendezvous on Day 187 used the system for approximately 4 hours. Acquisition was made at a range of 209 nmi. The rendezvous was conducted with the Saturn Workshop in a solar inertial attitude, as in the previous rendezvous. Again, some predictable periods of loss of contact resulted from the abnormal look angles. The total Saturn Workshop system operating time was 247.5 hours for the entire Skylab mission with five cycles of operation. Of this, approximately 234 hours of operation occurred during the first manned period to provide heat to the coolant loop. The system met or exceeded all of its design objectives during the mission and was considered to be an operational system at the end of the mission with no degradation in capability.

Four modified Apollo tracking lights provide a visual means of locating the Saturn Workshop for rendezvous during orbital night. The Apollo sextant or the optical alignment device can be used for long range acquisition. Each tracking light consists of a flash lamp mounted on the solar observatory deployment assembly, an electronics unit, and interconnecting control cables. The minimum light intensity is 1000 beam-candle-seconds in a region which is essentially a

90-degree cone centered about the Saturn Workshop +X axis. The tracking lights flash at a rate of 50 to 65 flashes per minute with a maximum flash duration of 0.3 millisecond. Normally two tracking lights are active and two are for backup. An automatic control switches to the backup lights if the primary lights fail. Control of the lights is normally provided by the digital command system; however, an onboard switch is available for crew use. The electronic timer provides an alternate means of deactivating the tracking lights when the spacecraft is out of range of a tracking station.

The tracking light subsystem operated for each rendezvous. On Day 12, the first crew twice required tracking lights for rendezvous for 3 hours and 2 hours, respectively. The lights were first reported by the crew at a distance of 390 nmi, which is in excess of the expected range. Rendezvous of the second and third crews were conducted with the Saturn Workshop in the solar inertial attitude. This attitude caused some abnormal viewing angles for the tracking lights, resulting in some predictable periods of loss of contact between the command module and the Saturn Workshop. During the final rendezvous on Day 187, the tracking lights operated for approximately 4 hours. The crew did not report when the tracking lights were first sighted.

Eight colored docking lights are mounted on the Saturn Workshop. The colors of the lights serve as references in maneuvering the command module, usually from about 200 feet out from the Saturn Workshop to within 50 feet of the docking port. The discrete antennas are also illuminated with white lights so that the crew can avoid the antennas during flyaround and docking maneuvers. The docking lights are normally controlled by the digital command system; however, an onboard switch provides the capability for crew control in the event of an extravehicular activity or a rescue mission. The individual lights are not redundant since the loss of several lights would not jeopardize docking. The docking lights were operated during the period of rendezvous termination until docking, or approximately 1.5 hours for each manned period.

There are two docking targets mounted on the Saturn Workshop, one near each docking port. These are used in conjunction with the optical alignment set, which is mounted on the window frame in the command module. The target and alignment set allow the orientation of the vehicle within the 10 degree variation from center range required for probe and drogue mating. The docking target system was used extensively during the Apollo missions, so the procedures and crew training were well developed before the Skylab mission. The first crew made several docking attempts because of probe problems; however, neither they nor the second or third crew made any comments about the alignment system operations.

## 5.8 ANOMALIES

Most of the anomalies described in this section were the results of component failures in equipment in inaccessible locations, so examination of the failed items was not feasible. In most cases tests, simulations, and data analysis localized the failures. The use of redundant equipment, the selection of alternate modes and procedures, and, where possible, the replacement of failed hardware enabled satisfactory performance of the instrumentation and communications system throughout the mission.

### 5.8.1 Laboratory Low-Level Multiplexers

Intermittence of one of the low-level multiplexers was probably a failure of the nonredundant pulse steering diodes used in the counter module inputs. The exact nature of the failure was not determined. Noise on the reference voltage and seven other measurements on another low-level multiplexer was most probably caused by a change in "turn-on" characteristics of a second-tier switch. The noise which occurred on the first eight channels of all of the low-level multiplexers and nine channels of the programmer on Day 224 was most likely caused by a varying voltage propagated on the 3-millivolt (15 percent) reference line connected to the affected multiplexer and programmers.

### 5.8.2 Laboratory Transmitter A (10-Watt)

The loss in the RF output power of transmitter A was attributed to the RF power amplifier section's degrading to an unusable level. The cause was not determined.

### 5.8.3 Solar Observatory RF Coaxial Switch

Approximately 7 hours after the Saturn Workshop was launched, high reflected RF power was exhibited by the solar observatory RF link consisting of transmitter 1, coaxial switch 1, RF multicoupler 1, and the aft antenna. The reflected power was 8.6 watts; the normal value is less than 0.5 watt and the specification value is less than 2.0 watts. Transmitter 2 incident and reflected power remained normal on both forward and aft antennas.

The possible location of the fault was limited to the coaxial switch and the RF multicoupler. The coaxial switch failure simulation corresponded more closely to the actual flight condition; therefore, it was assumed that the switch was the failure point. The switch operated properly in the transmitter "to forward antenna" position.

### 5.8.4 Audio System Channel B

The first playback of the recorded voices of the second crew over audio channel B was unintelligible at the ground station. The crewmen also noted that the intercom speaker volume on channel B was lower than that on channel A. The crew performed a diagnostic procedure unplinked from the ground whereby each of the redundant earphone amplifiers was disabled, one at a time. The earphone amplifiers were operating satisfactorily, since the speaker volume decreased equally when each of the circuit breakers was turned off. The crew then disconnected the tape recorder and recorded channel B voice on tape recorders 2 and 3, which resulted in garbled voice playbacks from both recorders. In a ground unit test, the power supply providing regulated power to the tape recorder amplifier and one of the two channel B earphone amplifiers was reduced from the normal +20 vdc to 16 vdc. The tape recorder amplifier circuit then produced low frequency oscillations and garbled voice similar to the problems encountered in flight. At the same time the voice output at the speaker decreased. It was concluded that the cause of garbled channel B audio was a degraded power supply for its recorder amplifier. With only one tape recorder amplifier remaining for the rest of the mission, an alternate mode of recording voice was developed and a modification kit was fabricated on the ground and carried up by the third crew.

The third crew reported on Day 261 that a noise on the channel B intercom loop which had been present for a short period on Day 132 was back again, occurring at a rate of approximately 6 hertz. The crew implemented a procedure which switched the backup audio center onto the channel B circuit. The problem still existed, so troubleshooting of the earphone amplifiers of audio channel B was initiated. The two buffer amplifier circuit breakers were opened and closed sequentially, and the noise disappeared when circuit breaker number 1 was opened. It was concluded that the noise source was the secondary channel B earphone amplifier. Opening circuit breaker number 1 disabled the remaining operational tape recorder amplifier of channel A. Therefore, it was necessary to close this circuit breaker during voice recording. This procedure was acceptable since there were only 16 days left in the mission before final deactivation. No other action was taken.

#### 5.8.5 Video Tape Recorder

The video tape recorder lost playback capability on Day 81. It showed only a carrier modulation corresponding to a dc bias input to the transmitter. The bias level indicated a failure in the video demodulator circuitry. Four printed circuit boards were brought back for analysis.

The failure was found to be an open circuit in a variable coil in the demodulator. The defective coil was removed from the video limiter-demodulator board and subjected to temperature shocks. High temperature reopened it. X-rays of this coil and a control sample from the same lot showed insufficient coil wire wrapped around the terminal and the absence of a solder fillet at the junction. The coils were microsectioned, and the inspection confirmed the X-ray finding. Further analysis showed that the defect was not caused by an external circuit or electrical transient anomalies. Very few data were lost as a result of the anomaly.

#### 5.8.6 Television Monitor

One of the two television monitors on the solar observatory control and display panel lost its raster on Day 132. Telemetry data showed that the monitor was not using any electrical current. Failure simulation testing showed that when power was switched on a normal monitor, a characteristic current transient always occurred on the input power line because of capacitor charging in the low voltage power supply. This was not observed when the onboard unit was turned on and off. It was concluded that the isolation diode for the low voltage power supply had failed open.

During the remaining week of the second manned period, the crew was constrained to one monitor. This imposed an undesirable procedural constraint on the crew. A new monitor was sent up for the third manned period. It was installed and operated normally for the rest of the mission.

## SECTION 6

# ATTITUDE AND POINTING CONTROL

The Saturn Workshop was designed with no major articulating elements because of the use of existing hardware, cost limitations, and other development considerations. The fixed solar arrays, antennas, and experiment mounts made attitude control very important for general orientation. Some experiments required reasonably precise orientation and stability, and the solar observatory required a very precise pointing control.

Many techniques were available for attitude maneuvering and stabilization in low Earth orbit, and several factors influenced the selection of the control system. Aerodynamic effects, gravity fields, and magnetic fields as well as onboard disturbances had to be overcome for stability. Attitude change rate and mission lifetime requirements also influenced the selection of maneuvering techniques. Onboard disturbances were minimized by techniques such as nonpropulsive venting. External torques were also minimized where possible by keeping the X principal moment of inertia axis in the orbit plane and reducing aerodynamic asymmetry. No provisions were made in the Saturn Workshop for linear acceleration for orbit trims. This function, when required, was to be performed by the command and service module.

A summary of the design and performance of the system is presented, including a brief description of the anomalies. More detailed information is contained in reference 3.

### 6.1 ATTITUDE CONTROL

#### 6.1.1 System Requirements

The system requirements for attitude control for the Saturn Workshop were unique. The attitude control system had to accurately point the solar observatory at the Sun and the Earth observation sensors at the Earth, and to maneuver the 100-ton Skylab to various attitudes. The system was required to perform these operations in Earth orbit for a period of 10 months without repair or resupply. The system had to be capable of pointing the solar observatory at the Sun with an accuracy of  $\pm 6$  arc-min about the Saturn Workshop X and Y axes, and  $\pm 10$  arc-min about the Z axis. This, the vehicle's primary attitude, is called the solar inertial attitude (fig. 6-1). The pointing stability required in this attitude was  $\pm 9$  arc-min for 15 minutes about the X and Y axes, and  $\pm 7.5$  arc-min for 15 minutes about the Z axis. The system had to be capable of pointing up to  $\pm 4$  degrees away from the sunline while maintaining this accuracy and stability. For the Earth observation sensors, the required attitude was with the -Z axis pointed at the Earth's center and the +X axis in the direction of the orbital velocity vector (fig. 6-1). This, called the Earth observation or Z local vertical attitude, had to be maintained to within 2.5 degrees. The system had to be capable of maneuvering the Saturn Workshop from the solar inertial attitude to any other attitude, holding the new attitude inertially fixed, and then returning to the solar inertial attitude.

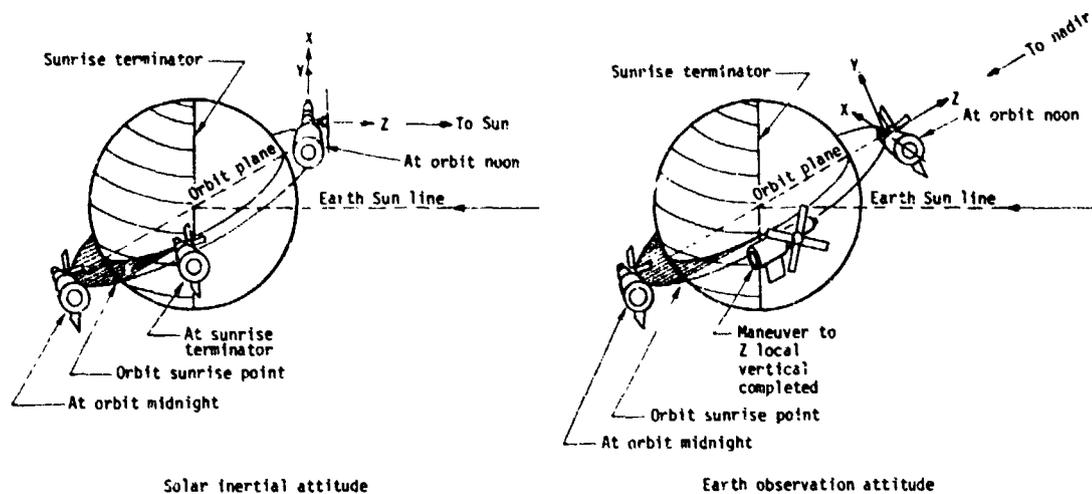


Figure 6-1.- Typical orbital geometry illustrating two attitudes.

Other requirements were established for rendezvous and orbit trim. The rendezvous attitude pointed the  $-Z$  axis toward the center of the Earth, and the  $-X$  axis in the direction of the orbital velocity vector. This attitude was to be maintained to within  $\pm 12$  degrees about the Saturn Workshop  $Y$ -axis, and  $\pm 6$  degrees about the  $X$  and  $Z$  axes. During orbit trim maneuvers, the system was required to maintain the solar inertial attitude within 10 degrees.

#### 6.1.2 System Design

The attitude control system was designed to satisfy the above requirements in an orbital environment which included gravity gradient torques applied by the Earth's gravitational field, aerodynamic torques, vent torques, and crew motion disturbances. Analysis showed that a gas reaction control system capable of meeting the design requirements for a 10-month period would require a prohibitive amount of propellant, so the momentum exchange system which was already designed into the solar observatory was upgraded and adopted as the Saturn Workshop's primary control system. This system required only electrical power for operation, and could meet the system design requirements for 10 months with a minimum weight requirement.

This was the first manned spacecraft to use large momentum control gyros for attitude control, the first to manage control gyro momentum by maneuvering in the gravity gradient field, the first to use a digitally implemented control system with in-orbit reprogramming capability, and the first to use an attitude reference based on a four-parameter calculation. A digital computer was provided to perform the functions of attitude control, maneuvering, navigation and timing, momentum management, and redundancy management. A simplified block diagram of the attitude control system is presented in figure 6-2. Figure 6-3 shows several elements of this system installed on the solar observatory. Sun sensors, a star tracker, and rate gyros provided the Saturn Workshop control system with position and angular rate information. A cold gas thruster system was provided for auxiliary use.

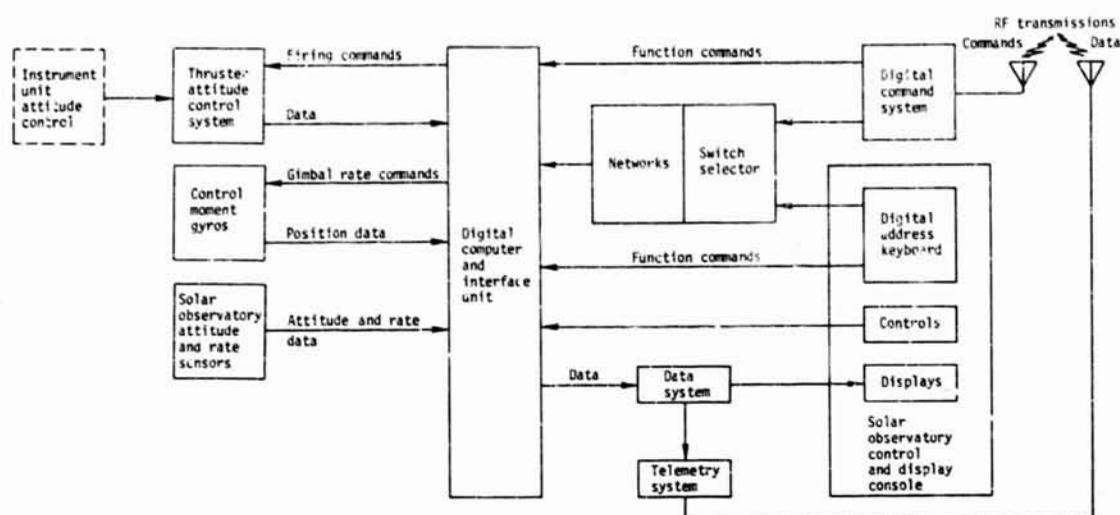


Figure 6-2.- Attitude control system.

- |                        |                       |                                     |
|------------------------|-----------------------|-------------------------------------|
| A. Control moment gyro | C. Digital computers  | E. Workshop computer interface unit |
| B. Star tracker        | D. Rate gyro packages |                                     |

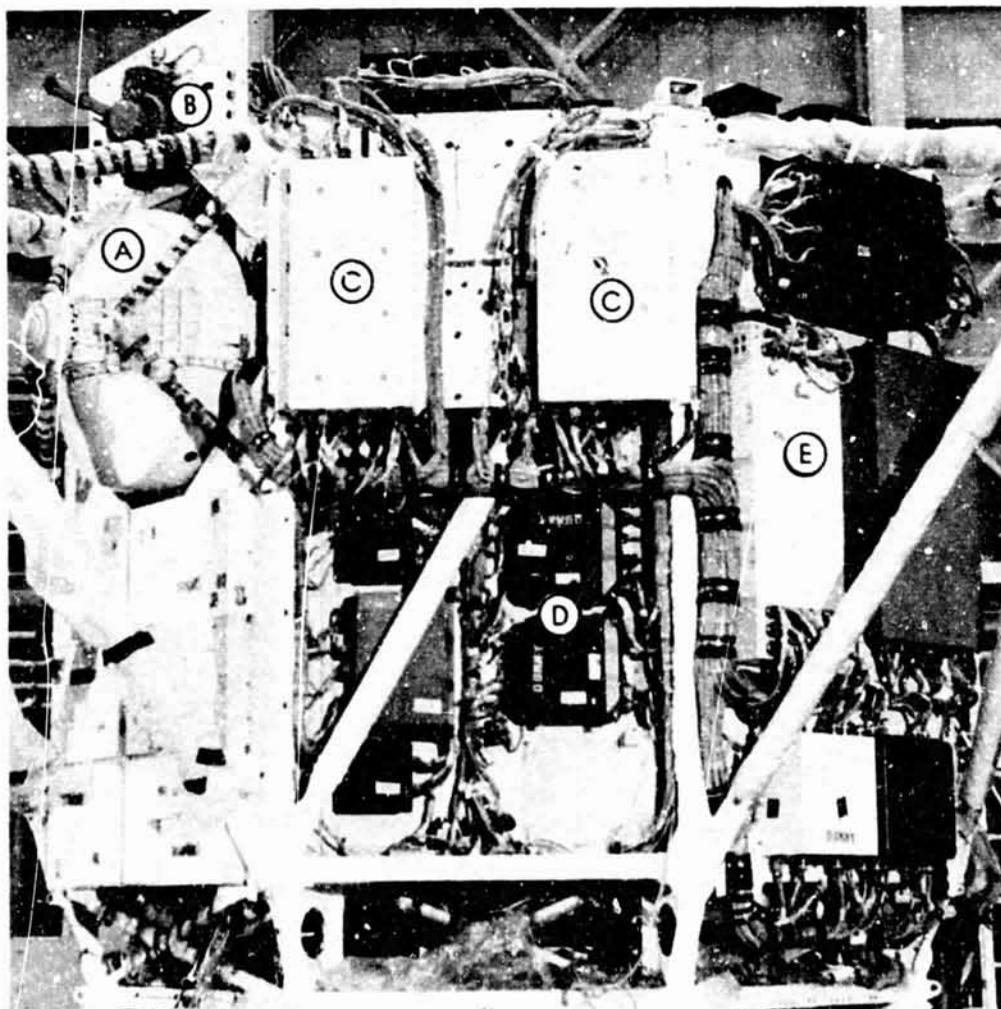


Figure 6-3.- Solar observatory in manufacture.

**Digital Computer.**- The digital computer and interface unit are mounted on the solar observatory structure (fig. 6-3). The digital computer maintains the attitude reference, performs navigation and timing computations, commands the control moment gyros and thrusters to maintain attitude or to maneuver as required, manages the control gyro system momentum, manages the redundant system components, and provides system mode control, data handling, and experiment support. Computer redundancy was supplied by a backup digital computer. Computer memory or the actual computer program could be modified by ground command or by the crew, by means of the digital command system.

**Control Moment Gyros.**- Three double-gimballed gyros are mounted orthogonally on the solar observatory structure (fig. 6-3 and 6-4). They are oriented so that when all three are in the zero position their momentum vectors (spin axes) are parallel to the Saturn Workshop X, Y, and Z axes. Each contains a 0.53 meter diameter, 65.8-kilogram wheel which is double-gimballed to provide two degrees of freedom within the limits of mechanical stops. Inner gimbal travel is limited to 160 degrees, while outer gimbal travel is 350 degrees. The wheels spin at about 9000 rpm and have angular momentum of 3000 N-m-sec. The digital computer commands the gimbals to drive at the required angular velocity with maximum rates set at 7 deg/sec. The gimbals move the momentum vectors, applying the desired torques to the Saturn Workshop. Any two of the three control moment gyros have sufficient momentum for control. Control moment gyro details are shown in figure 6-5.

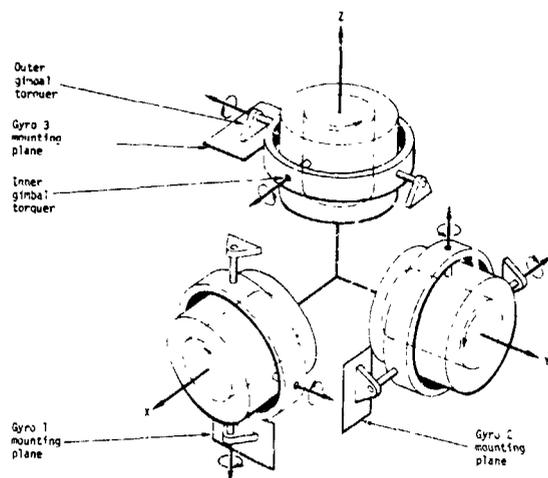


Figure 6-4.- Control moment gyro orientation.

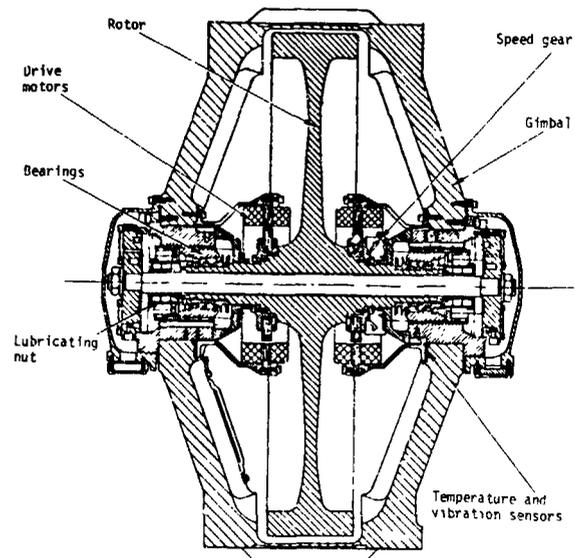


Figure 6-5.- Cutaway of control moment gyro wheel and inner gimbal.

**Rate Gyros.**- Three groups of three rate gyros are mounted orthogonally on the solar observatory structure (fig. 6-3). Each rate gyro can operate in a fine mode with a range of 0 to 0.1 deg/sec, or a coarse mode of from 0 to 1.0 deg/sec. The fine or coarse mode is commanded for all nine rate gyros simultaneously by the computer, depending on rates. Outputs are used by the computer to calculate velocity and position. Normally, any two rate gyros in each axis are paired, with the computer averaging their outputs for rate information, while the third is a spare.

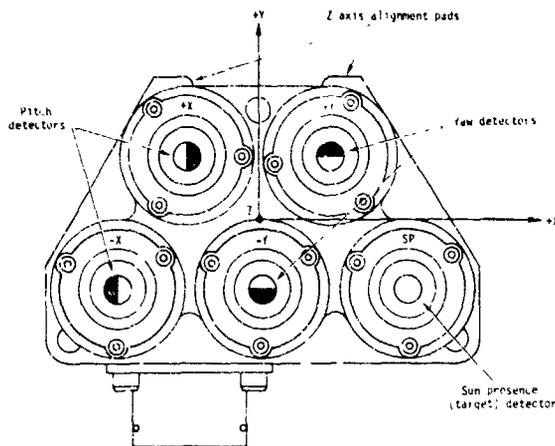


Figure 6-6.- Acquisition Sun sensor optical assembly.

provide an offset pointing capability of up to 4 degrees from the sunline. The Sun sensor is designed to be completely redundant with two independent systems operating at all times.

Attitude in roll about the sunline is measured by a star tracker mounted on the solar observatory structure (Fig. 6-3 and 6-7). It is oriented so that the outer gimbal axis is parallel to the Z axis and is capable of operating in an automatic search-track mode, in a manual tracking mode, or in a shutter closed-hold mode. When the star tracker is tracking a known reference star, the computer uses the outer gimbal position to calculate the position in roll about the sunline relative to the plane of the ecliptic. There is no redundant tracker.

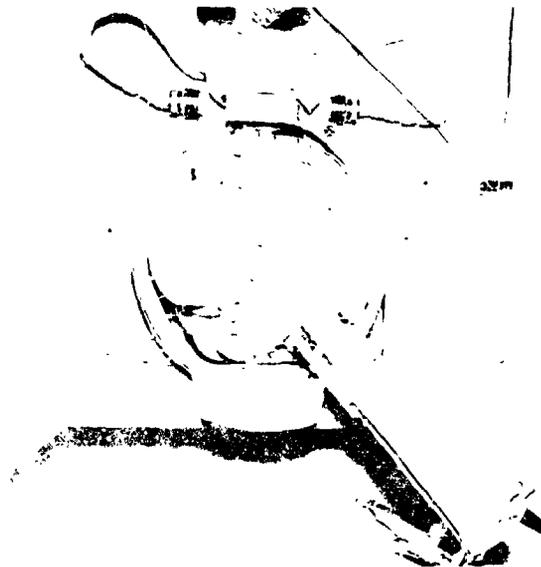


Figure 6-7.- Star tracker.

Thruster Control System.- This blowdown system, located on the workshop structure, as noted in figures 6-8 and 6-9, consists of six cold gas (nitrogen) thrusters and their associated control electronics and propellant storage spheres. Initial gas storage pressure is about 22 N/mm<sup>2</sup>. Gas pressure and thrust level decay as the nitrogen supply is depleted. The impulse of a single firing is kept constant at about 22 N-sec by lengthening the firing time as the thrust level decays. There are no backup thrusters; however, redundancy is provided in control circuitry and valving. The system is used for attitude control after launch vehicle separation and before spinup of the control moment gyros. It also assists the control moment gyro system in controlling the attitude when control moment gyro momentum approaches saturation. In addition, should the attitude error exceed 20 degrees, the computer switches to thruster-only control and inhibits the control moment gyros. Thruster system control can also be commanded by the crew or from the ground.

Sun Sensor and Star Tracker.- Attitude relative to the sunline is measured during orbital day by a two-axis Sun sensor mounted on the solar observatory structure. The two Sun sensor optical assemblies (fig. 6-3 and 6-6) comprise two pitch and two yaw detectors plus a Sun presence detector. The pitch and yaw detectors are mounted in pairs with semicircular occulting baffles on opposite sides. When the detectors are facing the Sun, the output signals cancel out, giving a null indication. When the detectors are tilted away from the sunline, the unbalanced output provides the magnitude and direction of the offset error. The outputs are used by the computer to update its calculations of attitude. The outputs may be biased to

### 6.1.3 Operational Modes

The attitude control system can operate in any one of several modes. These modes can be selected by the crewman at the solar observatory control and display console or by ground control by means of the digital command system. The modes are controlled by the flight program in the computer, and include:

a. Standby - This mode is used when no attitude control is required. In standby, the control moment gyro gimbal rate commands are zeroed, and no thruster firing commands are issued. The computer monitors the angular velocities and maintains the attitude reference calculations.

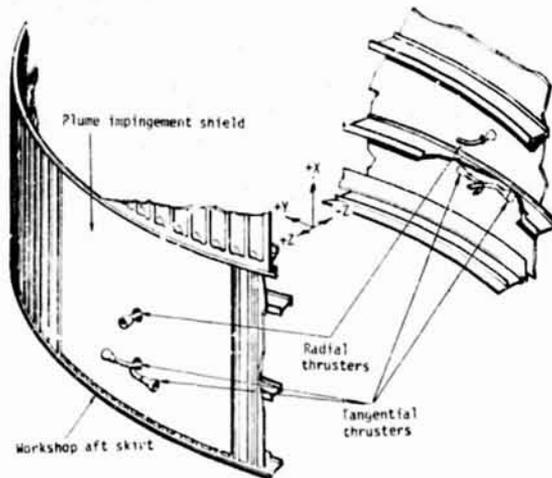


Figure 6-8.- Thruster system component locations.

held inertially fixed or can be maneuvered to any desired attitude. The attitude is maintained by the control moment gyro system with the thruster control system as a backup.

e. Attitude hold (thruster control system) - This mode is identical to the previous mode except that the attitude is maintained by the thruster control system.

f. Earth observation mode - This mode is used to point the Earth observation experiments (fig. 6-1). The -Z axis is pointed toward the Earth along the local vertical and the X axis pointed along the velocity vector in the orbital plane. Rotation about the Y axis is at orbital rate. The attitude is maintained by the control moment gyro system with the thruster control system as a backup.

b. Solar inertial - This is the normal mode of operation for the attitude control system. In this mode the Z axis is pointed toward the Sun and the X axis is close to the orbital plane (fig. 6-1). The attitude is maintained by the control moment gyro system with the thruster control system as a backup, and momentum management maneuvers are performed during the night portion of each orbit. The solar observatory fine pointing control system is not activated in this mode.

c. Solar observation mode - This mode is identical to the solar inertial mode except that the solar observatory fine pointing control system and the solar experiments are activated.

d. Attitude hold (control moment gyros) - In this mode the attitude is

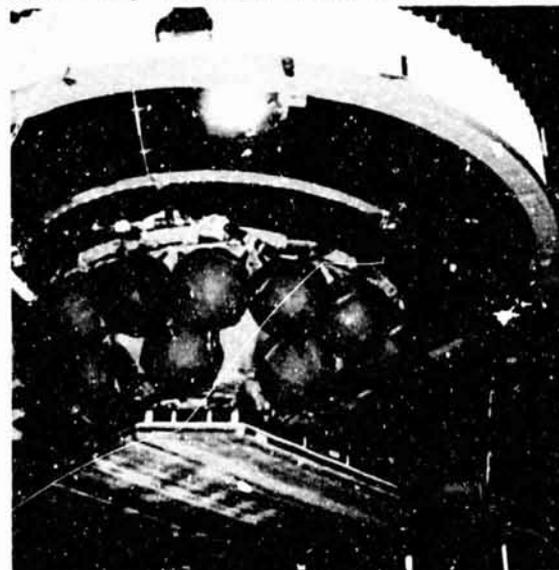


Figure 6-9.- Thruster system nitrogen bottles.

g. Rendezvous mode - This mode is identical to the Earth observation mode except that the workshop -X axis is pointed along the velocity vector in the orbital plane. This mode was desired for use during rendezvous with the command and service module but was never used because of the desire to conserve thruster propellant.

The flight program in the computer maintains several parameters for the control system. They are briefly described.

Attitude Reference.- The attitude reference is a four-parameter computation based on Euler's rotational equations. The computation is used to calculate the attitude with respect to the attitude reference coordinate system and the orientation of the attitude reference coordinate system with respect to the solar inertial coordinate system. Saturn Workshop angular velocities are used for the computation of the equations. During orbital day in the solar inertial and solar observation modes, the Sun sensor outputs are used for updates. Once per orbit, at midnight, information from the star tracker outer gimbal is also used to update the computations.

Navigation and Timing.- The flight program maintains knowledge of the position in orbit relative to orbital midnight. It also calculates significant orbital event times and determines the day-night orbital phase and the time remaining in each phase. It computes the relationship of the orbital plane to the equatorial plane, and the orientation of the Sun vector relative to the orbital plane. It also maintains mission time. All the computations assume a circular orbit and ignore the movement of the Earth about the Sun and the regression of the longitude of the orbital ascending node between orbital midnights. To compensate for the resulting drift, all navigation parameters can be updated by ground control by means of the digital command system.

Attitude Control.- The flight program uses the computations to determine the attitude error. The rate gyro outputs are compared with the commanded rates to determine the rate error. The attitude and rate error signals are combined, modified by the appropriate gains, passed through digital bending mode filters, and used to drive the control law logic circuits for the control moment gyros. The control law section uses the three commands from the bending mode filters and the orientation of the control moment gyro momentum vectors to generate the six control moment gyro gimbal steering and rotation commands. These commands are modified to minimize the possibility of driving the gimbals into the stops, and to keep the gimbal rates within limits. If control moment gyro momentum approaches saturation, the flight program fires a single thruster to reduce the momentum in the axis most affected. Should the attitude error exceed 20 degrees in any axis, the flight program would switch control to the thruster control system, which would then reduce the attitude errors to zero. In thruster-only control, the attitude and rate errors are combined, passed through digital bending mode filters, and used to drive the thruster control system. The control law logic circuitry provides thruster firing commands to reduce rate and attitude errors to zero when the control deadbands are exceeded. Thruster pulse and full-on firings are generated by a weighted sum of position and rate errors. If this sum exceeds control law ledge limits, full-on firings are commanded. The commanded Saturn Workshop angular velocity is limited by limiting the attitude error used in the control equations. Figure 6-10 defines the phase plane of the thruster-only control law.

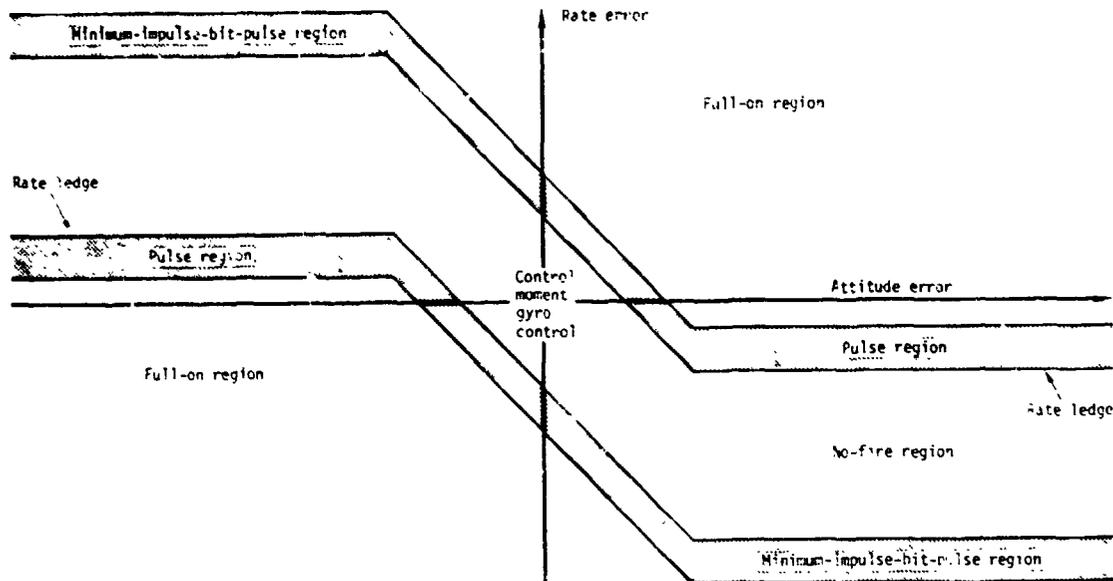


Figure 6-10.- Thruster control law phase plane.

Maneuvers.- Two types of maneuvers could be performed, offset pointing and general purpose. Offset pointing maneuvers can only be performed in the solar inertial mode, are limited to  $\pm 4$  degrees about the X and Y axes, and are performed by biasing the Sun sensor error signal input to the computer by the desired amount to produce an attitude error. The system then reduces the attitude error to zero, which produces the desired offset. These maneuvers can be commanded either by the crew at the control and display console, or by ground control by means of the digital command system. General purpose maneuvers involve maneuvering to arbitrary time variant or inertial attitudes, and include Earth observation maneuvers, attitude hold maneuvers, and control moment gyro system momentum desaturation maneuvers. These maneuvers use a constant maneuver rate which is dependent on the desired maneuver angle and the predicted time to complete the maneuver. The control moment gyro control law logic is used in a rate-only mode to force the Saturn Workshop angular rotation axis to coincide with the desired maneuver rotation axis. The maneuvering scheme specifies the desired attitude reference coordinate system position with respect to the solar inertial attitude, based on the maneuver commands. This position is constantly compared to the Saturn Workshop attitude to generate an instantaneous attitude error between the position and the desired position. A maneuver time is specified and decremented as the maneuver progresses. Rate commands are computed by dividing the attitude errors by the remaining maneuver time. When the remaining maneuver time reaches 60 seconds, time in the computation is frozen at 60 seconds, which causes the rate commands to decrease gradually to zero. When the maneuver time runs out, the control law logic is switched back to using rate error plus attitude error, and any remaining position errors are reduced to zero. For Earth observation maneuvers, the attitude reference coordinate system is forced to rotate about the Y axis at orbital rate. After the Earth observation attitude is attained, the attitude reference coordinate system is tracked to maintain attitude.

Control moment gyro desaturation maneuvers are commanded by the momentum management subroutine in the flight program. The basis for momentum exchange is the conservation of momentum. The total system momentum is made up of Saturn Workshop momentum plus control moment gyro momentum and is constrained so that the

change in Saturn Workshop momentum is zero. Any change in Saturn Workshop momentum caused by external torques, such as gravity gradient and ventings, is compensated for by an equal and opposite change in control moment gyro momentum. Gravity gradient and aerodynamic torques are cyclical, however, and therefore store up and release momentum, so their effects on the control moment gyros is slight. Any noncyclic external torques acting on the Saturn Workshop will cause a net control moment gyro momentum buildup. Because of the limited momentum storage capacity of the control moment gyros, this momentum buildup will eventually cause control moment gyro saturation and loss of attitude control about the axis of saturation.

Several techniques are used to avoid momentum saturation and reduce momentum accumulation. The noncyclic gravity gradient torques are minimized by maintaining the axis of minimum moment of inertia (the X axis) in or near the orbital plane. The saturation effects of the remaining noncyclic disturbance torques are nullified by maneuvering to produce controlled gravity gradient bias torques during the night portion of each orbit that tend to desaturate the control moment gyro system. The flight program obtains information about gyro momentum accumulation by sampling the normalized components of the momentum four times during the day portion of each orbit. This information is used to establish a momentum bias, a momentum drift, and a change in momentum drift. A weighted summation is then used to form body axis momentum commands. These momentum commands are used to develop three successive three-axis maneuvers which are performed during the night portion of each orbit. These maneuvers produce controlled gravity gradient bias torques which tend to reduce the control moment gyro momentum. The third maneuver also includes a Z-axis rotation which optimizes the position of the X axis relative to the orbital plane for the next orbit. In addition, a single thruster is fired around the appropriate axis if momentum approaches saturation. If the gyros become saturated, they can be caged to the normal momentum configuration for the orbital position, and the thrusters fired to reduce the resulting vehicle rates to zero.

Redundant Components Management.- Failures which could cause loss of thruster propellant, loss of attitude reference, or loss of control are detected and eliminated automatically by redundant component management in the computer. The components monitored include the control moment gyros, the rate gyros, the Sun sensors, and the digital computer. Tests are performed to verify that each component is functioning properly. When failures are detected, the failed component is removed from the system. This automatic capability is backed up by a manual component switching capability at the control and display panel. In addition, component switching can be commanded from the ground by means of the digital command system.

#### 6.1.4 Mission Performance

First Unmanned Period.- At 19:07 Gmt on Day 1, near the end of the first orbit, spinup of the control moment gyros was begun and the digital computer entered the standby mode until control could be switched from the instrument unit's flight control computer. The temperature of rate gyro Z1 was increasing, and at 20:13 Gmt it went offscale high. At about the same time, the Y-axis rate gyro output began drifting at rates considerably greater than predicted. Attitude control transferred from the instrument unit to the solar observatory system at about 22:20 Gmt. At this same time, control was switched to the control moment gyro system. Three minutes later, the Z2 rate gyro temperature went offscale

high. At 5:17 Gmt on Day 2, the Y1 rate gyro (Y2) temperature went offscale high. Eventually, three more gyros making a total of six, became hot.

The rate gyro outputs continued to drift at greater rates than predicted. During the first 24 hours of attitude control system operation, excessive drift was noted in all three X-axis rate gyros, two of the three Y-axis rate gyros, and two of the three Z-axis rate gyros. The high drift rates were compensated in the digital computer program by changes uplinked from the ground; however, the drift rates often changed suddenly. This caused difficulty until the new drift rates could be measured and compensated.

After the loss of the meteoroid shield during launch, there was considerable experimentation to find an attitude that would keep temperatures within the workshop as low as possible, yet provide enough power to keep the Saturn Workshop operational. Finally, the docking adapter end of the Saturn Workshop was pitched 45 degrees toward the Sun. This reduced the workshop heating and maintained an adequate power output from the solar panels. The X axis was kept in the orbital plane to minimize control moment gyro momentum accumulation. This attitude was called the thermal attitude. In the thermal attitude, there was no way to update the digital computer attitude reference. As a result the rate gyro drift frequently caused the Saturn Workshop to drift out of the thermal attitude. Ground control monitored solar panel output and control moment gyro momentum to maintain knowledge of the Saturn Workshop's attitude, and sent commands when necessary to maneuver it back to the thermal attitude.

During the thermal attitude hold period, the many attitude control maneuvers caused a heavy expenditure of thruster propellant. Each maneuver had to be planned carefully to minimize use of the thrusters. The momentum management scheme, since it was designed to operate only in the solar inertial attitude, could not be used. Momentum management worked normally on one occasion during a temporary return to the solar inertial orientation on Day 2.

The only means used to desaturate the control moment gyros in this period was the reset routine. Because the reset routine caged the gyros to the specified momentum value for solar inertial attitude, resets could only be commanded at orbital points where solar inertial and thermal attitude normal momentum curves intersected. In addition, adequate ground station coverage was required for these points. Rate gyro drift caused movement of the X axis out of the orbit plane, and the resulting momentum bias caused frequent control moment gyro saturations and frequent resets, with the consequent high use of thruster propellant.

First Manned Period.- For rendezvous, the Saturn Workshop did not maneuver as planned to the rendezvous attitude, but remained in the required thermal attitude. High thruster gas usage continued as frequent control moment gyro resets occurred. Additional high gas usage was required when the crew in the drifting command module attempted to free the partially deployed solar array while the attitude control system was in the thruster-only control mode. Several unsuccessful docking attempts before hard dock was achieved also caused thruster firings. After the parasol thermal shield was deployed, the Saturn Workshop maneuvered to the solar inertial attitude and normal attitude control began. Thereafter, thruster use was low and usually resulted from maneuvers to other attitudes or significant venting.

Because of the early mission problems and the thermal extremes experienced by the vehicle, a manual switchover to the secondary computer system was performed on Day 27. This was a test to verify that the redundant capability of

the computer subsystem was functional. The crew selected the secondary computer and enabled automatic switchover. The secondary computer system turned on and began operating properly. During the next 2 days, the program was updated to the level of the primary computer by uplinking three program patches necessary to compensate for the continual rate gyro anomalies and the vehicle mass change caused by loss of solar array wing 2 and the meteoroid shield.

On several occasions during the first manned period the star tracker erroneously locked onto objects other than the required star. A procedure was formulated which avoided these situations, and thus alleviated the problem.

Second Unmanned Period.- During the second unmanned period, the time of the desaturation maneuver was decreased by about 20 percent to prevent extending these maneuvers into the daylight portion of the orbit. This precaution was necessary to protect an experiment whose aperture door was failing to operate automatically. Before the second manned period the desaturation time was increased to normal and remained so for the rest of the mission.

The Y3 and Z1 rate gyros produced extremely noisy outputs because of high temperature and were turned off on Day 59. Others continued to drift with rates as high as 18 deg/hr, two orders of magnitude greater than specified. The initially observed drifts were successfully compensated with biases uplinked to the digital computer. As time passed in the mission, the magnitudes of required bias corrections lessened. During this period investigations to determine the cause of high drifts were completed. A crash program began to prepare a package of supplementary rate gyros that could be used should additional failures threaten to cause mission termination.

No thrusters were used during the second unmanned period since the attitude control system performed normally with the vehicle in the solar inertial attitude.

Second Manned Period.- On Day 76 the second crew rendezvoused with the Saturn Workshop and began a flyaround inspection. Because of reaction control jet impingement on the parasol thermal shield, the flyaround was ended earlier than planned. The impingement forces also caused increased use of the Saturn Workshop's thrusters. The command and service module docked to the Saturn Workshop with the attitude control system in the attitude-hold, thrusters-only mode.

On Day 79 the star tracker shutter failed to close when desaturation maneuvers began. The crew also tried unsuccessfully to close the shutter using manual control. The same shutter problem recurred later. In all cases, the shutter would close correctly after several hours. A protective procedure was developed to prevent permanent damage to the star tracker photomultiplier by exposure to reflected light from the Earth or the Sun while the shutter was open. This procedure included parking the tracker so that it looked at the dark, rear surface of the solar arrays.

During a normal desaturation maneuver on Day 91 certain events occurred that resulted in loss of attitude control and considerable thruster gas usage. After an automatic Z-axis redundancy management test failed, additional momentum was commanded to bring the controlling rate gyro to the required rate. The additional momentum requirement forced the control moment gyro into saturation and siphoned momentum from the X axis at the same time. The X-axis momentum change produced

an uncontrolled rate and resulted in a 20-degree attitude error buildup in the X axis which caused a high rate alarm and an automatic switch to thruster-only control. During this period, the crew noted that panel meters indicated that control moment gyros 1 and 3 were on a stop. The gimbals were actually caged. During a later test, the false reading problem was observed only on the control moment gyro 1 measurement.

Because of the continuing rate gyro problems, one of the foremost concerns was the installation of the six supplementary rate gyros that were provided for contingency. The crew mounted the "six pack" in the locking adapter, and on Day 103 performed an extravehicular activity to complete the installation by making the cable connections to the solar observatory. Since the rate gyros are essential to the attitude control system, no attitude control was possible during the cable switching period. The command and service module was not used for control because of problems in its reaction control system. The following procedure was developed to allow the vehicle to drift during the switching of the gyros:

- a. In thruster-only mode, drive the gyros to normal momentum cage.
- b. Change to gyro control to allow attitude errors in the thruster dead-band to be brought to zero.
- c. Change to standby mode for free drift, but return the gyros to normal momentum cage, which provides approximate compensation for gravity gradient torques.
- d. Perform wiring changes.
- e. Return to gyro control and reacquire solar inertial attitude.

The supplementary rate gyros were installed in the system and operated satisfactorily.

On Day 106 calibration maneuvers were made to establish supplementary gyro alignment to vehicle axes. Maneuvers of approximately 5 degrees were made about each axis while the control system data were collected by ground support. Analysis of the data by the mission support team showed the misalignment was very small and no compensation in the flight program was required. On Day 119 a vehicle stability test using solar observatory data verified that stability was within bounds acceptable for future viewing of the Comet Kohoutek.

On Day 130 a maneuver was made to point the solar observatory at a star for X-ray photography. The maneuver was successful and used minimum thruster gas. The maneuver technique was later used extensively in the Comet Kohoutek studies.

Third Unmanned Period.- Between the second and third manned periods the attitude control system performed very well, with no thruster firings.

Third Manned Period.- On Day 190, the crew modified the lower body negative pressure vent so that it vented into the waste tank instead of directly overboard. This decreased the disturbance torque which the venting caused.

Control moment gyro 1 failed between tracking stations on Day 194 at approximately 8:15 Gmt. At the preceding tracking station (Honeysuckle), control moment gyro 1 phase A current was observed to increase by 65 milliamperes, bearing 1 temperature increased 5°C, and wheel speed decreased 120 rpm. At acquisition of signal at Bermuda (8:42 Gmt), the phase A current was 2.06 amperes, bearing 1

temperature was 82°C, and wheel speed was indicating 0 rpm. A speed of approximately 3800 rpm was inferred from the wheel currents. Beginning at 8:50 Gmt, the control moment gyro 1 brake was applied for 7 minutes and control switched to the two-control-moment-gyro mode.

The failure of control moment gyro 1 caused an increase in thruster propellant use and a curtailment of maneuvering until a program could be evolved using the computer two-gyro control law program. Subsequent procedures enabled full operation of mission objectives and minimized thruster use.

Additional maneuvers were made to support the extensive study of Comet Kohoutek during this period. The attitude control system maneuvered Skylab to aim the solar observatory at Mercury to verify instrument capability and maneuver accuracy. Two extravehicular activities were performed for photography of Comet Kohoutek.

The star tracker failed on Day 228. Telemetry data were analyzed and laboratory tests made to duplicate the failure. Operation of the star tracker was stopped, so the Z-axis update capability was lost. Alternate techniques to calculate the vehicle roll reference were begun on the ground.

Tests and Orbital Storage.- After the third crew departed, the following engineering tests were performed on the attitude control subsystems that had experienced problems and on redundant hardware or capabilities that had not been used during the mission:

- a. Control moment gyro 1 attempted spinup - Power was applied to the wheel motor for 8.5 hours. No wheel spin was detected.
- b. Rate gyro power up - All rate gyros were turned on and those which had exhibited erratic outputs or offscale temperatures were observed. Operation was not significantly different from that observed previously.
- c. Digital computer reprogram - The computer was successfully reprogrammed twice, once using the digital command system and once using the memory load unit.

The procedures for the memory load test included a switchover to the primary computer and loading a selected program from the onboard recorder while over the Goldstone ground station. The proper commands were sent, and telemetry verified that the desired program had been loaded into the computer.

The test of using the digital command system for memory loading was more complex, requiring two passes over Hawaii to complete the process. On the first pass, a command to execute the load was sent to the computer at 16:08 Gmt. As the Saturn Workshop passed over Vanguard, telemetry verified proper response to the Hawaii command. At the next acquisition of signal by Hawaii, at approximately 17:00 Gmt, the ground tape recording of the computer program was started, transmitting the data to the computer. Telemetry verified that the 16,384-word load was successfully completed 11 seconds later. This marked the first time that an inflight computer had been loaded using a radiofrequency uplink.

On Day 272 Skylab was maneuvered to a stable gravity gradient attitude with the docking adapter pointed away from the Earth. The attitude control system was turned off at 20:00 Gmt on Day 272.

### 6.1.5 System Performance

Dynamic Stability.- The dynamic behavior of the attitude error as the solar inertial attitude was acquired for the first time using control moment gyros (on Day 2 at 11:48 Gmt) is shown in figure 6-11. During an unmanned, quiescent period on Day 2, observed pointing accuracies in all axes were 0.4 arc-min with an uncertainty of 0.4 arc-min. Stability for 15-minute intervals was also  $0.4 \pm 0.4$  arc-min. Jitter was observed to be about 0.4 arc-min/sec. During a manned, quiescent period on Day 14, the pointing accuracies observed were as good as they were in the unmanned period, but the stability and jitter errors increased slightly. Worst stability was 1.4 arc-min, and worst jitter was 1.2 arc-min/sec. This performance observed early in the mission was well within system performance requirements.

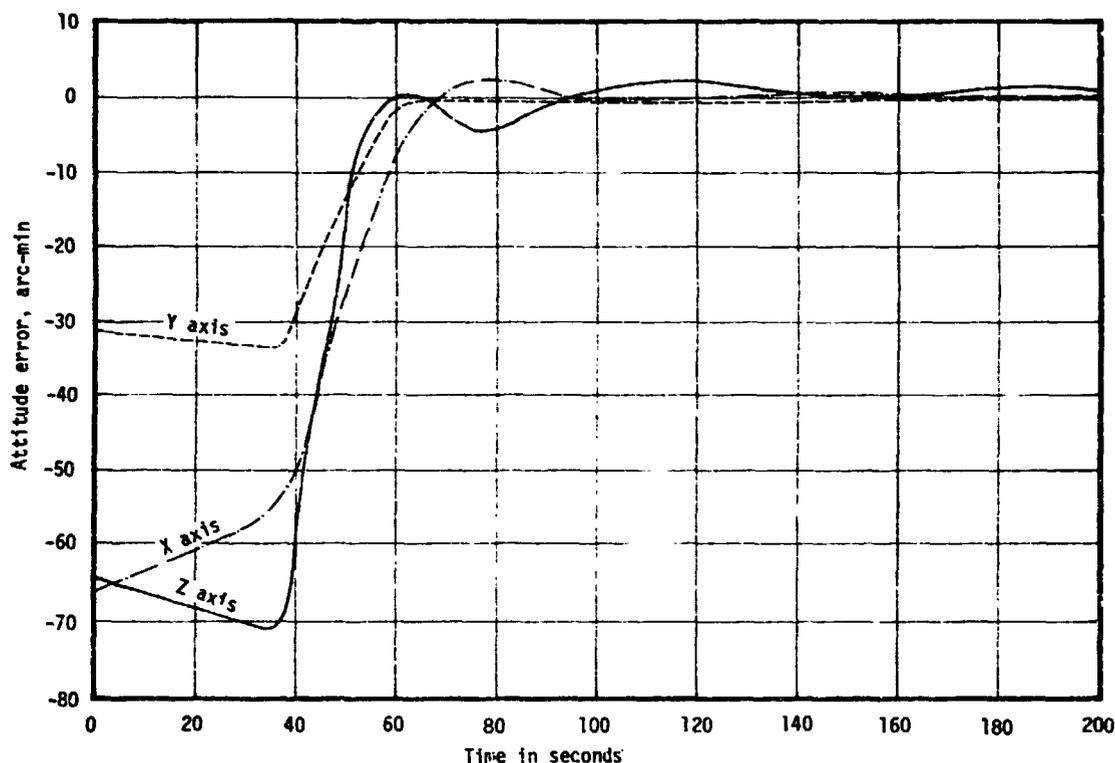


Figure 6-11.- Attitude error during initial solar inertial attitude acquisition with control moment gyros.

Special Maneuvers.- The first week of almost constant maneuvering in the thermal attitude gave confidence in the vehicle maneuvering capability. After the installation of the thermal shield and the reacquisition of solar inertial attitude, a wide variety of attitude hold maneuvers were performed. These maneuvers were for rate gyro calibration, Comet Kohoutek observation, and X-ray stellar photography.

The first rate gyro calibration maneuvers were performed to check the scale factor of the rate gyros with respect to each other and with respect to the acquisition Sun sensor. After the installation of the six supplementary gyros, a second set of maneuvers was performed to check their alignments to vehicle axes. The maneuvers showed this alignment to be accurate enough that no additional computer compensation was required.

The study of the Comet Kohoutek was an unplanned opportunity requiring the development of ground software and flight procedures. In order to verify instrument capability and the accuracy of maneuvering to a bright target, a maneuver to point the solar telescopes at the planet Mercury was performed. The success of the maneuver led to the planning of a variety of maneuvers to investigate the Comet Kohoutek. Three types of maneuvers were required for Comet Kohoutek experiments. The first, consisting of a roll about the X principal axis, was for the purpose of observing Comet Kohoutek with experiment instruments viewing through an articulated mirror system located in the scientific airlock. As these maneuvers were about the X axis, there were usually no problems with thruster usage or gimbal stop problems. The only problems occurred with gimbal stops during two-gyro control for some of the largest maneuvers. The second type of maneuver pointed the solar telescopes at the Comet Kohoutek and maintained the X axis in the orbit plane. As these maneuvers required vehicle rates about both Y and Z axes as well as the X axis, they generally required extensive optimization in terms of maneuver rates, maneuver start and stop times, and momentum biases during two-gyro control to minimize thruster use. The third type of maneuver, used only during extravehicular activity, involved a rotation about the X axis to have the solar panel shade a camera held by a crewman.

Maneuvers for X-ray stellar photography, from the attitude system point of view, were similar to Comet Kohoutek maneuvers in that the solar observatory was pointed at a celestial reference and the X axis was maintained in the orbital plane. As the X-ray equipment had no independent sensor to help determine whether the target was within the field of view, which was only 6 arc-min, several maneuvers produced no data. This was the only case of insufficient maneuver accuracy. Target acquisition would have been possible with the Saturn Workshop's maneuvering capability if the crew had been provided with target detection capability.

Earth Observation Maneuvers.- In the mode used for Earth observation an orbital rate of approximately 0.064 deg/sec is present on the vehicle Y axis. Maneuver bias capability allows the maintenance of an arbitrary vehicle axis perpendicular to the local vertical. This capability was designed primarily for rendezvous, but was not used after rendezvous when the solar inertial mode proved feasible. It was used for Earth observation offset biasing with two control moment gyros and for insertion into the gravity gradient attitude at the end of the mission. Earth observation experiments were limited to solar elevations in the 0 to 60 degrees range to conserve thruster propellants and electrical power.

During the mission, it became apparent that Earth observation experiment performance constraints could be met by a variety of maneuvers and provide minimum thruster use with no thruster use or resets during data-gathering time. The parameters that could be varied included time and rate to maneuver in and out of the Earth observation attitude and control moment gyro momentum bias.

Earth observation passes were performed (if the solar elevation angle was less than 60 degrees) for data-gathering during the daylight portion of the orbit. After the loss of control moment gyro 1, the first Earth observations under two-gyro control required high thruster usage. This led to the technique of noon-to-noon Earth observations, possible when collecting data through orbital noon was not required. The advantage of noon-to-noon passes is that large maneuvers about the vehicle Y axis (large inertia axis) are not required during the maneuver to Z local vertical when the entry was at orbital noon.

The maneuver about the X axis to place the Z axis in the orbital plane is much less demanding from the momentum saturation aspect, because the X-axis inertia is much less than the Y- or Z-axis inertias. However, because of the misalignment of the principal X axis from the vehicle X axis, a Y-axis momentum bias was generated. This led to the technique of using the biased Z local vertical maneuver to maintain the X axis perpendicular to the vertical for the portion of the noon-to-noon Earth observations when data were not taken and maneuvering the Z axis to the vertical for collecting data. This tended to minimize momentum accumulation.

The prelaunch requirements had not allowed noon-to-noon Earth observations. However, power management procedures were developed to minimize the workshop power requirements. Thus, despite the loss of the solar array wing, power proved adequate for noon-to-noon Earth observations.

All Earth observation passes during the first two manned periods were made using three-gyro control, while all those during the third manned period were under two-gyro control. Excluding three Earth observation passes in which procedural problems occurred, the following comparison can be made. Forty-eight Earth observation passes were made under three-gyro control using a total of 1549 N-sec of impulse. Thirty-six were made under two-gyro control using 12,300 N-sec. Therefore, Earth observation passes performed under three-gyro control used an average of approximately 31 N-sec impulse, while those performed under two-gyro control used an average of 338 N-sec. Had the noon-to-noon maneuver not been used, thruster use under two-gyro control would have been much higher. There were 102 Earth observation passes scheduled during the Skylab mission, of which 93 were flown.

Desaturation Maneuvers.-- The Saturn Workshop was the first space vehicle to use maneuvers for momentum desaturation, and these worked extremely well. The desaturation scheme allowed two unmanned periods without any thruster use and saved a considerable amount of thruster gas during the manned periods.

One problem arose from the interface of the desaturation scheme and the star tracker, which gave a direct indication of the angle of the X axis to the orbit plane. When the tracker performed normally, this angle provided useful information for the momentum management scheme. However, the star tracker erroneously locked onto objects other than the required star on several occasions during the first manned period. This caused the outer gimbal angle input to be inaccurate. On one occasion the erroneous inputs were received just before calculation of the momentum desaturation maneuvers. This caused the momentum management scheme to produce less-than-optimum momentum states. To avoid these situations, star tracker control and outer gimbal use were inhibited, the desired star tracker gimbal angles were calculated by ground support software, the star tracker was manually positioned on the star by the crew at the control and display console, and computer star tracker control and outer gimbal use were resumed. This allowed a valid outer gimbal reading to be obtained, after which star tracker control and outer gimbal use were inhibited again. This procedure alleviated the problem with the star tracker readings. This time-consuming procedure to work around star tracker false lock-on could have been avoided by having the attitude about the sunline determined from momentum samples. While this information is not as accurate as that obtained from the star tracker, it is sufficiently accurate for momentum management and is independent of star availability or crew presence.

During the second unmanned period, the desaturation maneuver time was decreased to ensure that the desaturation maneuvers would be completed at night. This was done to protect an experiment with a failed door. Momentum management functioned well even though this smaller interval caused larger maneuver angles. The desaturation maneuver time was increased to normal at the start of the second manned period and remained so for the rest of the mission.

On two occasions, certain events that occurred during or just before initiation of gravity gradient desaturation resulted in loss of attitude control. Since the losses of control occurred during the active portion of the gravity gradient maneuvers, they were referred to as gravity gradient desaturation problems. The first loss of control occurred after a Z-axis rate gyro discrepancy was detected during the desaturation maneuver. The second loss of control resulted from action taken because of unexpected venting torques during an extravehicular activity. A significant condition existed during both instances of control moment gyro saturation. Once the system becomes saturated, the control law attempts to align the total momentum vector along the torque command vector. Also, because of proportional scaling, any additional torque requirement in the axis of the largest command will reduce the command in the other axes, altering the direction of the torque command vector. Momentum will, therefore, change in all axes because of the momentum vector's swinging to realign with the torque command vector. The X axis is the most sensitive axis to this phenomenon because of the lower control gains, smaller moment of inertia, and less momentum at rate limit despite the larger rate caused by the desire to prevent rate gyro scale switching. This condition is referred to as the X-axis momentum siphon effect. The relative difference in the momentum change among the three axes is small, but because of the small amount of inertia in the X axis, the vehicle rate about X is an order of magnitude greater than about the Y and Z axes.

Skylab proved the feasibility and desirability of using momentum control gyros. Control concepts worked as designed both for stabilization and maneuvering. The absence of outer gimbal stops would have simplified the software and prevented periods of attitude excursion. Greater gyro momentum, especially during two-gyro control, would have allowed less thruster propellant consumption. The outer gimbal drive and modified outer gimbal drive were designed to prevent a gyro from driving into an outer gimbal stop during maneuvers. They were primarily used in two-gyro operation and functioned well. Several times in the mission the additional availability of an outer gimbal drive logic at the end of a maneuver in the presence of large attitude errors would also have been desirable to prevent a switch to the thrusters-only mode.

The gimbal angle reset routine was developed specifically for the purpose of recovering from gimbal-on-stop situations and was automatically initiated in the flight program when this problem occurred. During the mission, this recovery capability was proved workable and essential to the control. It was automatically initiated several times during the mission.

The use of thrusters for momentum desaturation worked as designed, as did the reset routine. However, the relatively large rate deadband of 0.02 deg/sec in the X and Z axes and 0.01 deg/sec in the Y axis for the release to gyro control after a reset represented a momentum bias per axis of up to 1000 N-m-sec. The removal of these rates could again produce an undesirable momentum state.

Redundancy Management.- The automatic redundancy management scheme in the digital computer worked satisfactorily throughout the mission. Excessive rate gyro drift and scale factor errors occurred during the first 103 days. These were detected and corrected by reconfiguration of the rate gyro combinations used for control. No other significant failures occurred except the control moment gyro 1 failure, which was not detected by the redundancy management scheme because the test limits were not exceeded.

All the critical hardware components served by the computer and interface unit error detection program performed acceptably during the mission, so the computer automatic switchover capability was not used. The manual switchover capability was exercised twice during the mission, once on Day 27 to demonstrate the functional integrity of the backup computer system and again on the last day of the mission as part of a test which loaded the computer program by means of the memory loading unit.

Manual redundancy management was used extensively throughout the mission. The rate gyros were reconfigured many times because of high drift rates. The control moment gyro 1 wheel was turned off because of a bearing failure. A switch to the secondary computer was performed to verify that two computers were operational. The primary acquisition Sun sensor was turned off in support of a Comet Kohoutek experiment. No problems were encountered in manual redundancy switching.

Thruster Attitude Control.- The thruster attitude control system was pressurized for flight to 20.8 N/mm<sup>2</sup> 2 weeks before launch. Approximately 647 kilograms of ambient temperature nitrogen gas was loaded. The system was activated 9 minutes after liftoff of the Saturn Workshop launch vehicle, at which time firing commands were received from the instrument unit. Thruster control was transferred to the digital computer 2 hours and 10 minutes later. The thruster system was used as a backup for the attitude control moment gyro system for the duration of the mission.

Large gas consumption on Days 1 and 2 resulted from removal of orbit insertion transients and operation in a thruster-system-only mode until control was transferred to the control moment gyros. The total impulse usage rate remained high because the system was required to perform frequent control moment gyro resets while holding the thermal attitude. As thrust decreased, the digital computer command pulse width was increased to compensate so that the minimum impulse would remain fairly constant at approximately 22 N-sec. This minimum impulse value was maintained throughout the mission except at first on Day 1 when system pressure was high and for a brief period on Day 3 when the pulse width was changed from 50 to 80 milliseconds, which changed the impulse from 27 to 37 N-sec. This made system gain higher than desired, so the pulse width was returned to 50 milliseconds for several days.

At launch, the Saturn Workshop was loaded with 374,000 N-sec of impulse capability, and the predicted normal usage was 162,000 N-sec. The actual usage was 338,000 N-sec. Figure 6-12 shows the usage history. Maintaining the thermal attitude required high thruster gas usage. A large portion of the thruster fuel was used during such abnormal situations. Usage was also higher than expected during extravehicular activity because suit ventings caused more torque on the vehicle than predicted. The deflector was removed from the pressure control unit on subsequent extravehicular activities to minimize the venting torques. Normal usage was consistent with preflight predictions.

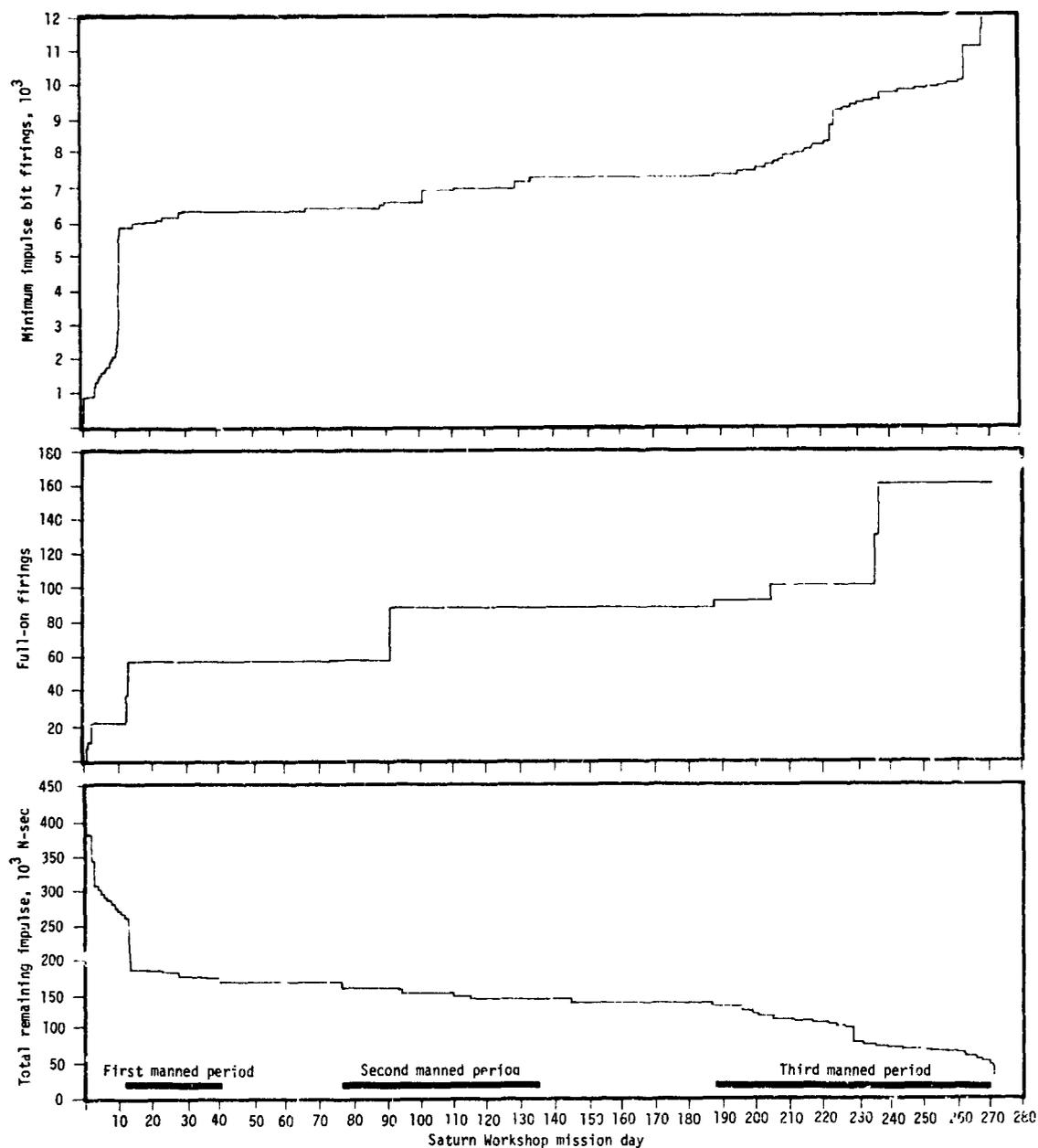


Figure 6-12.- Thruster usage history.

During the third manned period, thruster use rose after the failure of control moment gyro 1. Decreased momentum storage capability, coupled with increased maneuver requirements, especially for Comet Kohoutek observation, placed an added burden on the thruster budget. Mission planners had to minimize the use of thrusters while maintaining full experiment operation. The most significant conservation technique proved to be the noon-to-noon Earth observation maneuver.

Several computer simulations were used to predict thruster use requirements to aid mission planning. The simulation identified situations that would cause excessive firings and then verified propellant-saving alternatives. By providing accurate and realistic predictions, the simulations were invaluable for planning so that mission objectives could be met and even exceeded.

## 6.2 SOLAR OBSERVATORY FINE POINTING

The experiments mounted in the solar observatory require extremely accurate and stable pointing control. In addition, the observatory must be rolled about the sunline so that the various experiment optical slits will be in proper position. The requirements are offset pointing from the sunline of  $\pm 24$  arc-min with an accuracy of  $\pm 2.5$  arc-sec, a stability of  $\pm 2.5$  arc-sec for a 15-minute period, and a jitter of 1 arc-sec/sec, and roll about the sunline of  $\pm 120$  degrees with an accuracy of  $\pm 10$  arc-min, a stability of  $\pm 7.5$  arc-min for a 15-minute period, and a jitter of 3 arc-min for a 1-second period.

### 6.2.1 System Description

The solar experiments are mounted on a cruciform spar, enclosed by a tubular canister, and located within the basic structure of the solar observatory. The canister is attached to the structure by a three-degree-of-freedom gimbal mechanism-actuator assembly (fig. 6-13). The outer ring of this assembly is attached

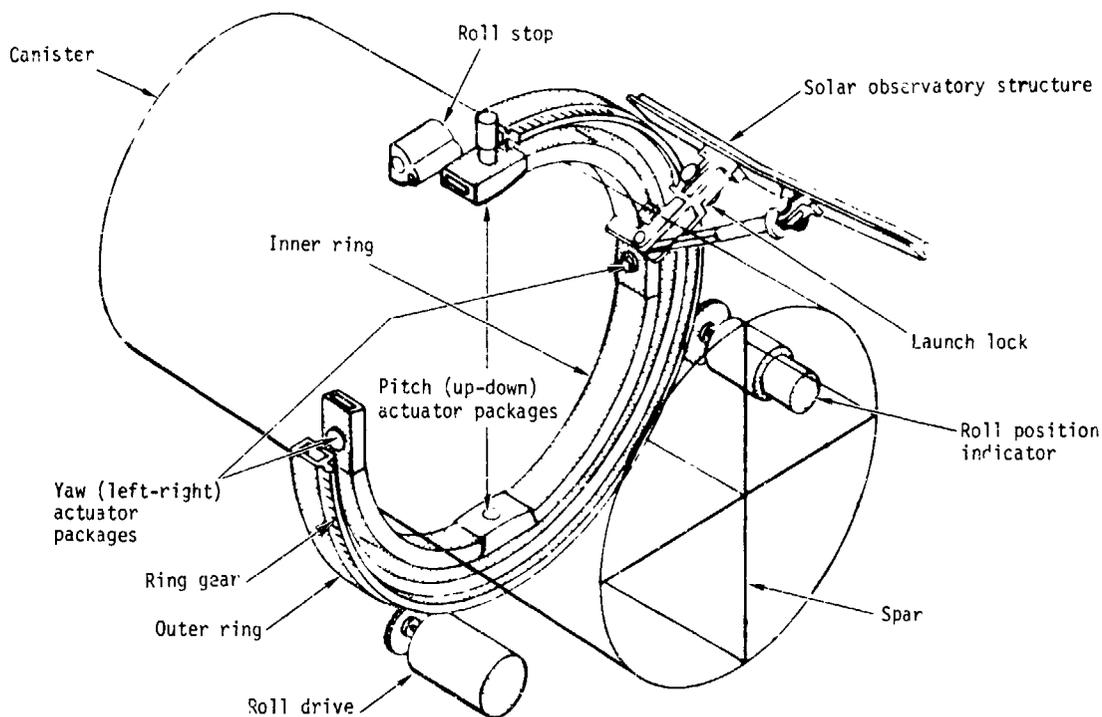


Figure 6-13.- Solar observatory fine pointing control mechanism.

to the solar observatory structure by four roller bearings, and is driven by an electric motor to roll the canister. The inner ring is attached to the outer ring by two frictionless flex-pivot bearings with  $\pm 2$  degrees freedom and is driven about the up-down axis by redundant actuators. The canister is attached to the inner ring by two frictionless flex-pivot bearings with  $\pm 2$  degrees freedom and is driven about the left-right axis by redundant actuators. Orbital locks constrain the rings and the canister while the solar observatory is not being used. A roll stop limits the roll to  $\pm 120$  degrees, to avoid damage to electrical cables. Launch locks protect the assembly from damage during launch. A roll resolver provides experiment roll position information to the digital computer.

Figure 6-14 is a diagram of the solar observatory fine pointing control system. Redundant fine Sun sensors are mounted on the spar to provide up-down and left-right error signals proportional to the angular displacement from the

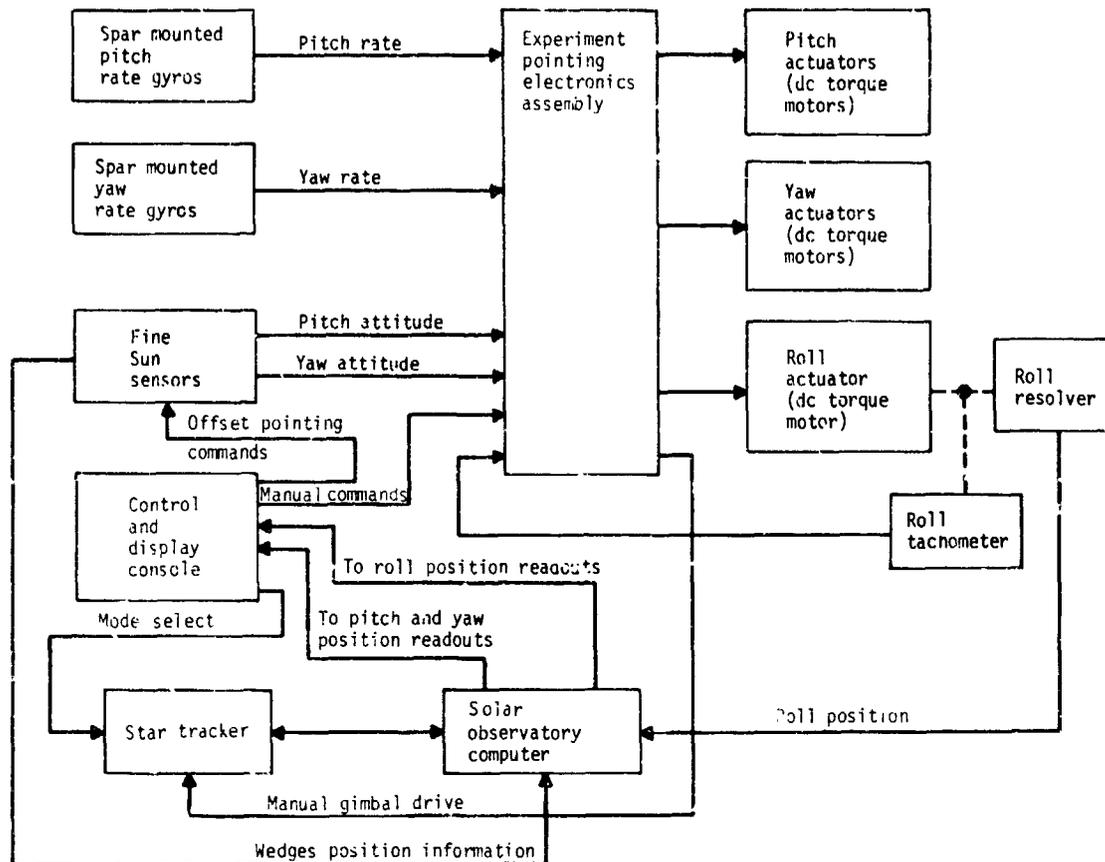


Figure 6-14.- Solar observatory fine pointing control system.

sunline, for pointing the spar at the center of the solar disk (fig. 6-15). Rotatable optical wedges are installed on the front of each fine Sun sensor optical channel to provide an offset pointing capability. Wedge position is transmitted to the control and display panel and the digital computer to provide experiment offset pointing information. Maneuver error information is transmitted from the fine Sun sensor to the experiment pointing electronics. Redundant rate gyros mounted on the up-down and left-right axes of the spar provide angular rate information.

The experiment pointing electronics assembly is an analog device with six primary channels and six redundant channels (fig. 6-16). It provides control commands for the up-down, left-right, and roll Sun sensor wedges and orbital locks. It interfaces with the solar observatory control and display panel, the digital computer for commands, and the telemetry data system. The digital computer provides commands to activate the solar observatory fine pointing control system at sunrise of each orbit, and to deactivate it at sunset. It commands the fine Sun sensor wedges for offset pointing of the experiments and maintains the wedge positions and the spar roll position for experiment data correlation. The computer also keeps the experiment telescopes pointed at a specific point on the solar disk while the canister is being driven in roll. This is done by commanding the fine Sun sensor wedges.

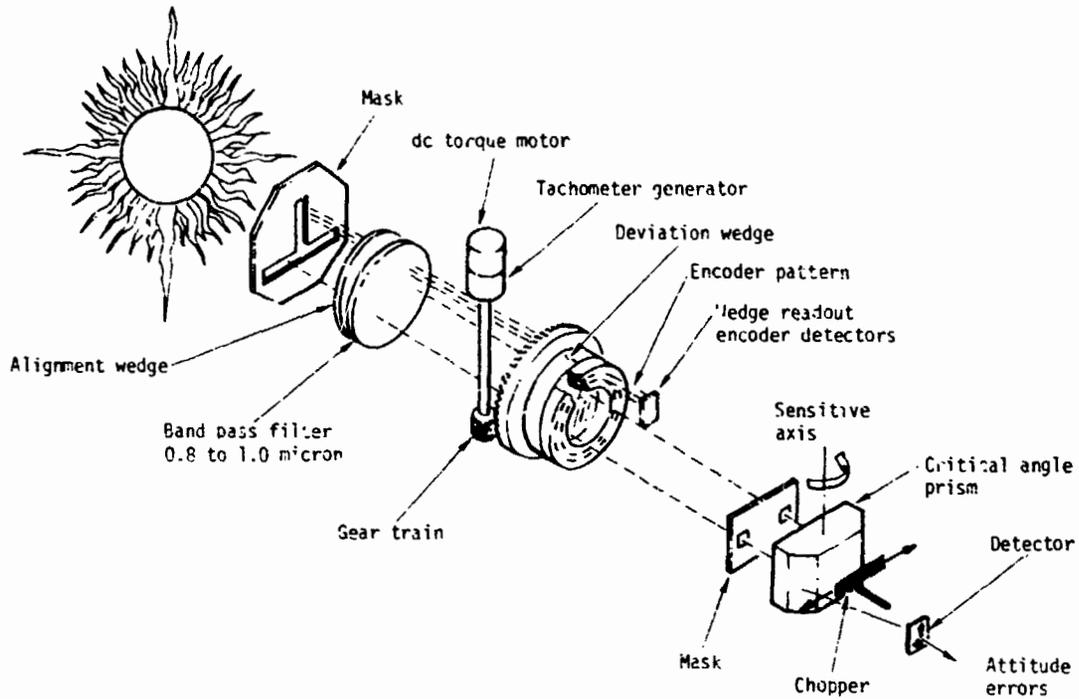


Figure 6-15.- Fine Sun sensor optical mechanical assembly.

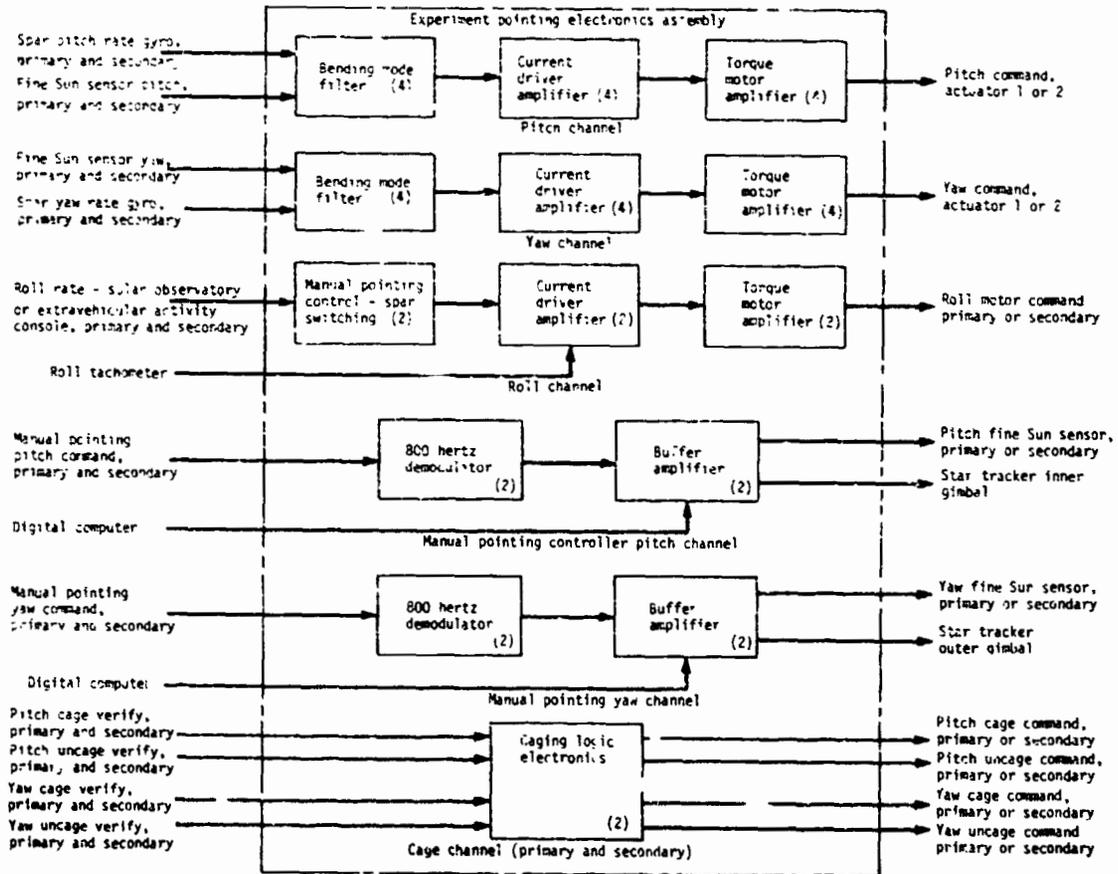


Figure 6-16.- Experiment pointing electronics assembly.

The solar observatory console provides means for manual control in addition to the automatic and ground control. The console also contains switches and status indicators which allow the selection of any combination of primary and secondary fine Sun sensors, rate gyros, experiment pointing channels, and orbital locks.

### 6.2.2 System Operation

Use of the solar observatory fine pointing control system was limited to the daylight portion of each orbit. The Saturn Workshop had to be in the solar inertial attitude with the computer in the solar observation mode. During the night portion of each orbit the fine pointing control system was powered but inactive. At true sunrise, the computer opened the fine Sun sensor protective door. At effective sunrise (when the Sun was above the atmosphere), the computer released the fine Sun sensor offset pointing wedges, and commanded the controller. The controller then uncaged the canister by disengaging the orbital locks, and began commanding the up-down and left-right actuators. At this point, the system was ready for use by the crew. At effective orbital sunset, the computer inhibited control of the fine Sun sensor wedges and commanded the experiment pointing controller. At true orbital sunset, the computer closed the fine Sun sensor door.

During solar observation operations, the crewmen were able to move about and perform other duties, since disturbances were isolated by the fine pointing control system. After the first manned period it was possible to perform some experiments by ground control. During the manned periods calibrations were made to determine the fine Sun sensor wedge angles necessary to point each of four of the solar experiment telescopes at the center of the Sun. The calibrated wedge angles were retained by the computer. The fine pointing control was used exclusively during the manned periods. Preliminary examination of solar data indicated that the system performed very well. The crew also reported that the system performed well and that manual pointing to within 1 arc-sec was possible with no perceptible drift.

Some problems were encountered with the system. The most serious of these was a failure of the canister primary up-down rate gyro. This failure occurred during unmanned operations on Day 64 while the Saturn Workshop was out of contact with a ground station. The canister began to oscillate about the up-down axis, and oscillated until the actuators overheated and seized. Shortly thereafter, the system was turned off. Three days later, after extensive analysis, the secondary up-down rate gyro was selected and the system was turned back on. No further problems were encountered with the up-down actuator. Because of this problem and the several attitude control system rate gyro failures which had occurred, a derived rate conditioner was developed and carried into orbit by the next crew. The derived rate conditioner was designed to use the fine Sun sensor output to develop canister rate information for the experiment pointing controller, and was to be installed in the event the second canister up-down rate gyro failed. It was never used.

Early in the first manned period the crew reported problems with the fine Sun sensor wedge position indicators. These problems were caused by a timing error in the computer which caused it to open the fine Sun sensor protective doors before orbital sunrise. The problem was corrected by updating the navigation parameters in the computer, and by the crew zeroing the fine Sun sensor wedge

position at the start of each orbital day. It was also noticed during this period that rolling the canister at the maximum rate (7 deg/sec) disturbed the entire vehicle. Maximum roll rate was not used thereafter.

On Day 185, during unmanned pointing operations, the up-down orbital lock failed to disengage at orbital sunrise, and the system was commanded off. After analysis, the secondary controller was turned on and the solar observation mode was commanded. The orbital locks disengaged normally. This problem occurred a second time on Day 201, with the same results. A detailed analysis showed that the problem was probably caused by intermittent mechanical binding of the primary orbital lock mechanism because of contamination. The problem did not recur.

### 6.3 ANOMALIES

#### 6.3.1 Rate Gyros

Two types of problems were experienced with the rate gyros during the mission: excessive drift and overheating. Analysis indicated that the high drift rates were caused by gas bubbles that formed in the gyro flotation fluid when the float chamber bellows was exposed to hard vacuum. This problem had been seen during thermal vacuum testing and was judged an acceptable risk because the high drift rates could be compensated in the software. The six supplementary rate gyros were modified to protect the float chamber bellows from the vacuum of space.

At 20:34 Gmt on Day 1 the first rate gyro temperature went offscale high. Eventually, a total of six rate gyros, X2, Y2, Y3, Z1, Z2, and the canister primary up-down, showed offscale high temperatures. All of the hot rate gyros produced very noisy signals, and eventually the Y3 and Z1 rate gyros began oscillating and were shut down. The primary up-down rate gyro on the experiment spar had similar symptoms and then failed on Day 64.

There was concern that as the rate gyros grew hotter and the float fluid viscosity decreased, they would become unstable. This apparently occurred with the Z1 and Y3 rate gyros. The hot rate gyros showed a change in scale factor. It was concluded that a transistor in the rate gyro heater circuit was failing in the on state.

The fabrication and installation of the six supplementary rate gyros greatly reduced the chance that the mission would be terminated because of three rate gyro failures in one axis. The original plan was to use the two supplementary rate gyros in each axis for control with the selected original rate gyro as a spare, but because of a single failure point which existed in the supplementary gyro power source, the remainder of the mission was flown with one supplementary gyro and the selected original gyro for each axis in control.

After supplementary gyro installation, rate gyros were no longer a problem, but the system did not have connections for 12 samples per second telemetry of the supplementary gyro outputs. The outputs were available on telemetry at one sample every 2.5 seconds. A second difficulty with the system was that supplementary rate gyro temperature measurements were not available on telemetry. As a result, the crew was required to monitor these temperatures periodically.

### 6.3.2 Control Moment Gyros

The failure of control moment gyro 1 on Day 194 was characterized by a rise in the wheel spin bearing temperature from a normal 21°C to a point just under the automatic shutdown temperature of 90°C, a decrease in wheel speed accompanied by an increase in wheel spin motor current, and failure of the wheel speed pickoff. The failure occurred while Skylab was between tracking stations and was first observed by the Bermuda tracking station. The bearing temperature at that time was 83.2°C and decreasing. The wheel speed was estimated from spin motor current to be about 3800 rpm, down from 9060 rpm before the failure. The failure was not detected by the redundancy management scheme, since the bearing temperature did not exceed the automatic shutdown temperature of 90°C. The spin bearing temperature did exceed the caution level of 74°C, and the caution was set. The caution indication was not seen by the crew, who were asleep. Shortly after detecting the failure while the vehicle was over Bermuda, ground control removed power from the wheel spin motor and applied the brake for 7 minutes. This probably did not slow the wheel appreciably. The computer switched to two-gyro control.

Preliminary analyses indicate the failure was caused by insufficient lubrication. The failure appeared to be progressive, with indications of bearing distress as early as Day 174. At the time, these indications were not considered significant. Control moment gyro 2 also had similar indications later, but did not fail. Unfortunately, the telemetered data were not sufficient to show all symptoms of bearing distress. Special temperature control and load reduction aided gyro 2 in completing the mission.

### 6.3.3 Star Tracker

Four major problems were encountered with the star tracker: tracking of contaminants, the shutter's sticking, photomultiplier tube degradation, and outer gimbal encoder failure. Workarounds were developed for the first three problems, but the encoder failure ended use of the star tracker.

The star tracker was activated at the start of the first manned period. It operated satisfactorily except for frequent disturbances when star acquisition was lost because of contaminants entering the field of view. If a particle reflecting light with an intensity above the photomultiplier tube's threshold enters the field of view, the particle will be tracked as a target star. This disturbance was noted 35 times during the first manned period and 4 times during the second manned period. Typical particles were generated by sloughing of paint and dust, outgassing, and venting from the vehicle (11.4.6).

Five times during the first manned period the star tracker shutter stuck open. The crew tried to close the shutter using control panel commands, but there was no response. The tracker was then positioned to point at the backside of a solar array to prevent damage to the photomultiplier tube. About 1.5 hours later, the shutter was observed closed when telemetry was acquired at a ground station. When the unit was turned off on Day 79, the shutter operated normally. Possible explanations were examined, and intermittent binding at some point in the shutter mechanism was found to be the most likely cause. The shutter problem caused temporary degradation of canister roll position information, but since the shutter problems cleared themselves after a few hours, the data loss was minimal. Workarounds required somewhat longer operating time by the crew.

On Day 101, the star tracker failed to acquire the target star, Alpha Crux. It was felt that bright light, presumably from the Earth's albedo, degraded the photomultiplier tube during a shutter anomaly. Exposure for as long as 20 minutes to light as bright as the Earth's albedo would permanently degrade the star tracker sensitivity by 50 percent. To determine if photomultiplier tube degradation had occurred, and by how much, a number of stars of different magnitude were selected and attempts to acquire each were made. Stars of 0.56 magnitude and brighter could be acquired and tracked. Comparison with ground tests indicated a sensitivity degradation of 30 to 50 percent. The photomultiplier tube degradation caused the loss of Alpha Crux as a target star. Since there were periods when both Achernar and Canopus, the primary target stars, were occulted, another star of sufficient magnitude, Rigel Kent, was found.

A failure was noted on Day 228 when the outer gimbal position indication went to zero and the outer gimbal rate signal recorded a constant output. Telemetry data were analyzed, and a laboratory test simulation duplicated the failure symptoms by interrupting the outer gimbal encoder output or the encoder lamp power. It was concluded that the outer gimbal encoder had failed and probably would not recover. This failure rendered the star tracker useless and it was turned off. The Z-axis reference provided by the star tracker was lost for the remainder of the mission. After Day 228 outer gimbal angles were computed by ground personnel using vehicle inertias and solar elevation. The crew later verified this method, using a sextant to measure star positions.

## SECTION 7 ELECTRICAL POWER

The Saturn Workshop's electrical power is supplied by two solar cell array systems. Each system is capable of providing approximately 4 kilowatts of continuous, regulated power. The laboratory system's components are located throughout the Saturn Workshop, especially in the airlock section. Its two solar array wings are folded against the sides of the workshop during launch and are deployed after orbital insertion. The solar observatory system's equipment is located on its exterior, except for the controls, which are in the docking adapter. Its four solar array wings are folded and restrained for launch and extended to their operating position after the solar observatory is deployed and locked.

The solar cell arrays intercept, collect, and convert sunlight into electrical power. Individual power conditioners consisting of a charger, battery, and regulator are associated with specific groups or panels of the solar arrays. During orbital periods when the Saturn Workshop is shaded by the Earth, energy stored in the batteries supplies power. The energy removed from the batteries during the dark periods is replaced during the following sunlight period and the remainder of the solar array energy is distributed to buses and networks to supply electrical load requirements. The power distribution system is protected by conventional safety devices, and paralleling of the two systems is possible. In addition, a power cable is pulled through the docking port into the command and service module by a crewman to supply the command module's systems after its fuel cell source is shut down. More detailed information can be found in reference 4. Figure 7-1 is a simplified schematic of the overall power system.

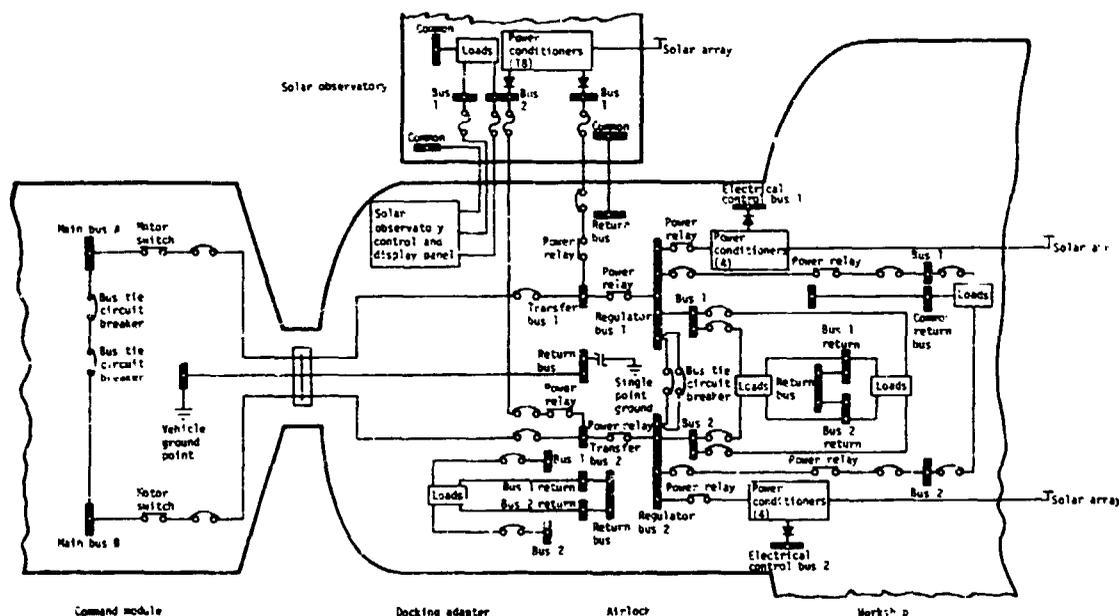


Figure 7-1.- Saturn Workshop electrical power systems.

## 7.1 MISSION PERFORMANCE

The laboratory telemetry and command systems were operated on ground power until approximately 3 minutes before liftoff, when they were switched to the laboratory batteries. No solar observatory systems were powered during launch. The solar observatory solar array was deployed approximately 28 minutes after liftoff. Deployment of the workshop solar array was commanded by automatic sequence at liftoff plus 52 minutes, but the array failed to deploy. Backup deployment commands were sent up with no success.

Two hours after launch, a command was sent that paralleled the two electrical systems and provided solar observatory power to the laboratory system buses. Power management procedures were initiated to ensure that the Saturn Workshop load demands would not exceed the capability of the solar observatory electrical power system. The goal of the power management operation was to limit the level of the solar observatory battery discharge. Spinup of the control gyros and activation of the workshop radiant heaters were delayed, and the docking adapter wall heaters were left on their low temperature thermostat controls until a full assessment could be made.

The Saturn Workshop was maneuvered out of the normal solar inertial attitude on Day 2 to prevent potentially destructive internal temperatures. This caused a reduction in the solar observatory power system capability and the requirement to manage power for the essential electrical loads became critical. Power management involved the use of ground computer programing to match flight plans to load requirements and to determine the power capability of the systems at various attitudes. The power capability is defined as the arithmetic average power available at the major buses during one orbital period.

The battery life is inversely related to the depth of discharge, cell temperature, and number of discharge-charge cycles. A 30 percent depth of discharge maximum was selected to ensure battery life through the 4000 or more discharge-charge cycles of the mission. The portion of the orbit in the Earth's shadow when the batteries are used is determined by the absolute value of the beta angle, which is the minimum angle between the orbital plane and the Sun vector. During the mission the beta angle varied between 0 and  $\pm 73.5$  degrees, the orbital plane being inclined to the equatorial plane by 50 degrees, and the equatorial plane being inclined to the ecliptic plane by 23.5 degrees. Orbit precession and perturbation caused dark periods for as long as 36 minutes. Figure 7-2 shows the beta angle and sunlight time for the Skylab mission.

The solar cells have their maximum output when their plane surfaces are perpendicular to the sunline, that is, when the angle of solar incidence is zero. This orientation exists in the solar inertial attitude. Neglecting other variables, the power capability is a cosine function of the angle of solar incidence. For thermal balance, an attitude with the docking adapter pitched  $45 \pm 10$  degrees from the solar inertial attitude toward the Sun was chosen. To maintain sufficient power, the mission rule to limit the 30 percent discharge level of the batteries was waived. The solar arrays were large enough to provide sufficient energy during the sunlight period to power the Saturn Workshop and to replace the power supplied by the batteries during 36 minutes of darkness. The batteries were operated at energy balance each orbit; that is, the only constraint on battery operation was that the batteries be recharged before entering each

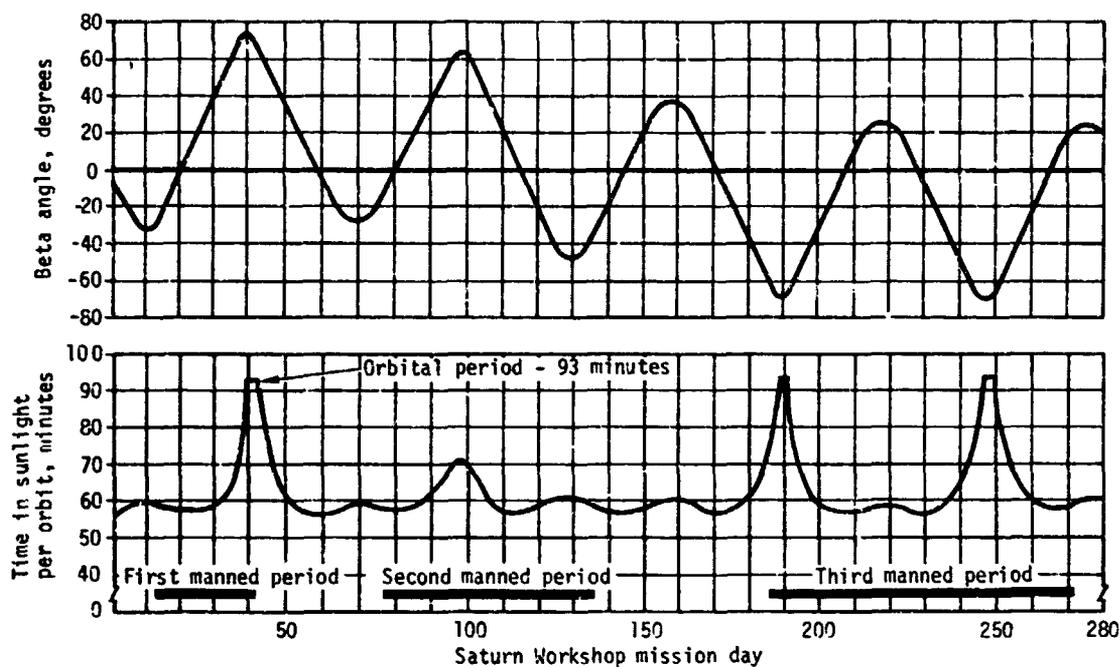


Figure 7-2.- Beta angle and time in sunlight per orbit.

orbital night. Figure 7-3 shows the power gained during the first unmanned period by using the energy balance constraint instead of the 30 percent battery discharge limit imposed originally.

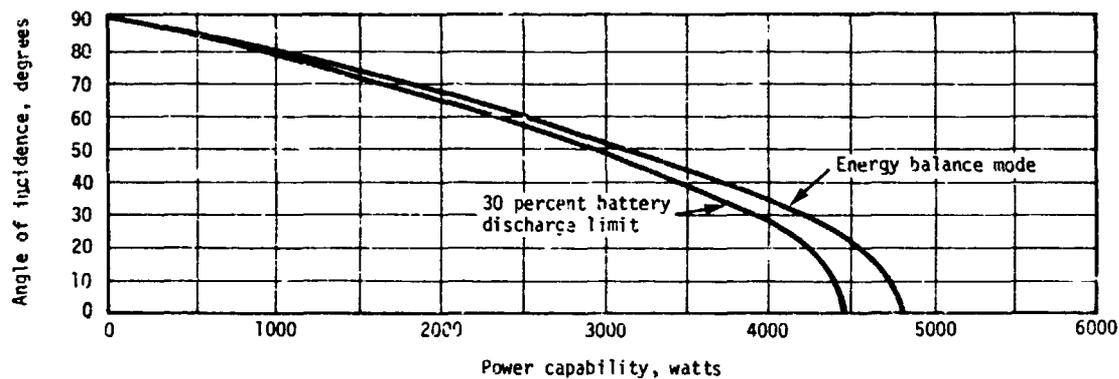


Figure 7-3.- Solar observatory power capability.

Power capability at the thermal attitude varied between 2700 and 3200 watts. A list of equipment that might be turned off (table 7-1) was prepared to be used as necessary to reduce the total load requirement to fit the capabilities of the power system. Not enough equipment could be turned off to reduce the total load to within this value, so the constraint to operate the system within energy balance was violated. Continued operation at this attitude resulted in a depletion of the battery-stored energy, and 8 batteries were automatically disconnected from the load buses, leaving the 10 remaining power conditioners to supply the entire load. The sunlight incidence angle was then decreased, and 7 of the power conditioners were reconnected to the buses during orbital daylight. Power conditioner 15 failed to respond to the attempts to reconnect it to the load buses.

Table 7-1.- List of Equipment To Be Turned Off As Needed During First Unmanned Period

Equipment	Load, watts
<u>Airlock</u>	
Wall heaters (15)	216.0
Coolant pumps (1 of 6)	85.0
Telemetry transmitters, 10-watt (3)	138.6
<u>Docking adapter</u>	
Wall heaters (8)	546.6
Docking port heater	19.9
Spare docking port heater	19.9
Tunnel heaters (2)	185.6
<u>Solar Observatory</u>	
Telemetry transmitters (2)	117.6
Valve control assembly	20.0
Pump inverter assembly	125.0

Analysis of this anomaly determined that the power conditioner 15 solar array contactor had failed in the open position. Attempts to close the contactor by ground and manual commands were unsuccessful. This reduced the available power by 5.5 percent.

During the first unmanned period the total load varied from 4400 watts average per orbit in the solar inertial mode to 2400 watts at the 60-degree pitch attitude. The solar observatory average load for this period was approximately 1600 watts. Since the solar observatory power system was providing all the power, the remaining 800 to 2800 watts was transferred to the laboratory transfer buses.

Figure 7-4 shows the average power capability from Saturn Workshop launch through the first manned period. It shows the effects of the thermal attitudes flown, the power increases after the parasol thermal shield deployment, the return to solar inertial attitude, and the activation of the laboratory power system after the laboratory solar array wing 1 was released and extended. Figure 7-5 shows the loads on Day 7. Although rigorous power management techniques were required for this time period, the power capability was sufficient to supply the minimum load requirements at the various attitudes and to protect the integrity of each electrical system. The voltage levels for this time period were substantially above the imposed minimum bus voltage needed by the components, ranging from 27.6 to 29 vdc. After the crew deployed the parasol thermal shield, the Saturn Workshop was returned to the solar inertial attitude. It remained in this attitude for the remainder of the first manned period except for occasional excursions to the Z local vertical attitude for Earth observations experiments.

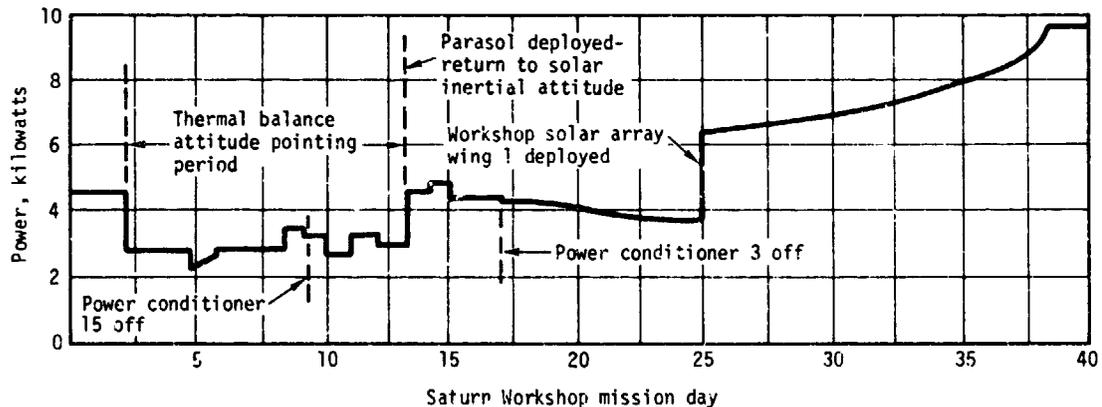


Figure 7-4.- Saturn Workshop power capability.

A further reduction in the power capability occurred on Day 17 when the power conditioner 3 output failed, leaving 16 power conditioners in operation. Additional degradation occurred on Day 24 when power conditioner 17 exhibited a reduced power output during specific orbital periods. The estimated loss of capability was 80 percent of the power conditioner 17 capability, or approximately 150 watts loss in the average solar observatory power. Subsequent

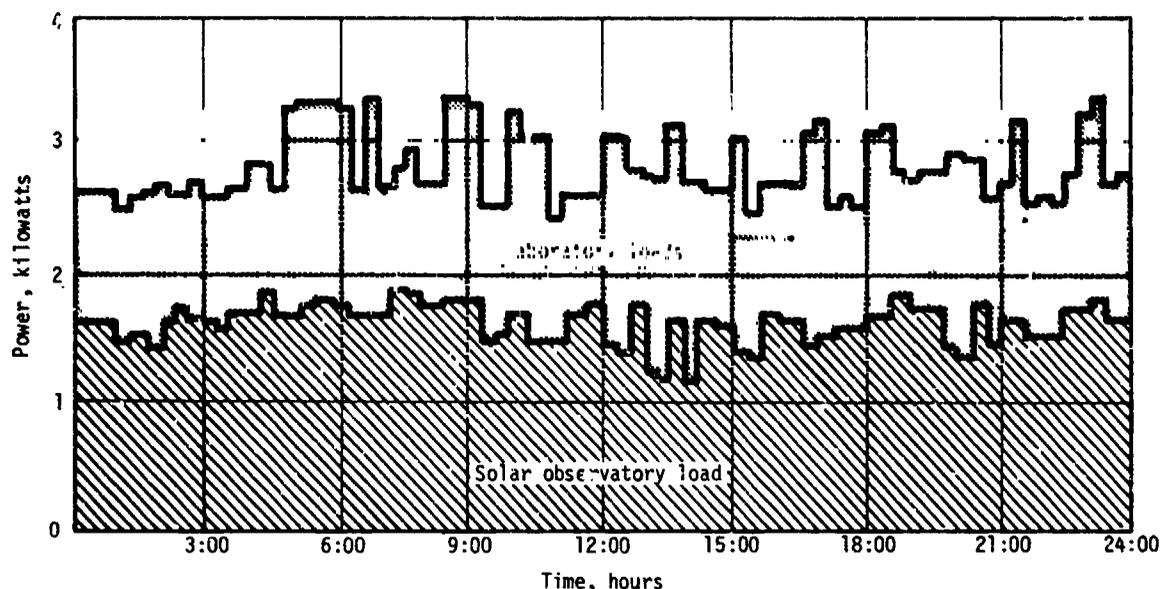


Figure 7-5.- Saturn Workshop electrical power loads on Day 7.

review of data indicated that this loss had initially occurred on Day 11. Additional power management was required to limit the total load requirements to compensate for reduction in power capability.

The solar observatory continued to supply the total electrical power requirement until midway through the first manned period, on Day 25. The command module's power was being supplied by its fuel cells, and it did not require any power from the solar observatory power system during this period. Load management was continued during this period to ensure that the load did not exceed the capability of the system. The docking adapter heaters were left on low temperature control and cycled from the ground when heat was required. Lights were turned on by the crew when in a particular work area and turned off when leaving the area. Use of food tray heaters was kept to a minimum. Recorders were operated only when essential data were needed. Other equipment which could operate automatically was kept in the manual control mode.

Skylab is placed in the Z local vertical attitude for performance of Earth observation experiments. This attitude positions the spacecraft with the -Z axis pointed at the center of the Earth and the +X axis in the direction of the velocity vector. This is shown in figure 7-6. This attitude mode reduces the electrical power capability except at one point. At orbital noon, the attitudes in solar inertial and Z local vertical are the same when the beta angle is zero. For this beta angle, when the Earth observations occur near orbital noon, only a small change in the incidence cosine is involved, resulting in a minimum loss of power capability. For Earth observations at other beta angles, the vehicle must be rotated about its longitudinal axis an amount equivalent to the beta angle, and the output power is decreased. However, at high beta angles the dark portion of the orbit diminishes, and the battery discharge during the night preceding the Earth observation pass is correspondingly reduced or eliminated. Thus the battery has a higher capacity at the start of the maneuver, which partially offsets the power loss caused by the non-solar-inertial attitude. Time spent in the Z local vertical attitude is a large factor to consider in maintaining the battery

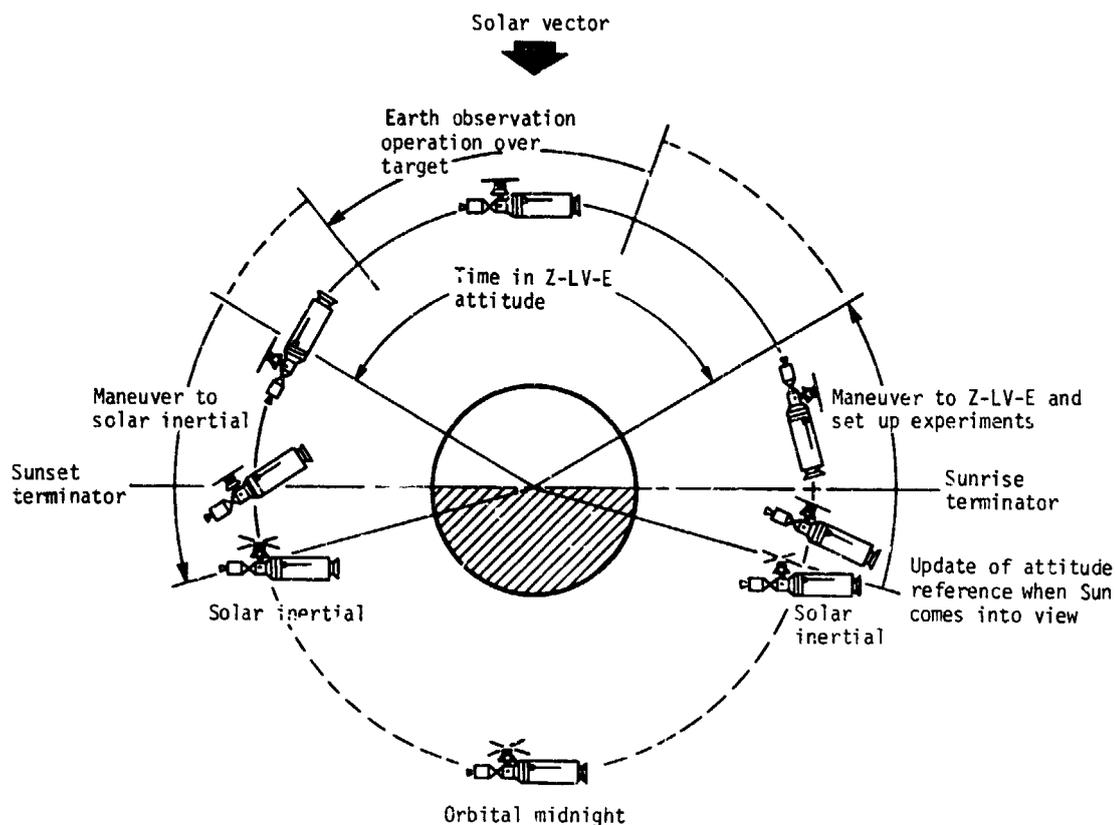


Figure 7-6.- Z local vertical maneuver.

percent of discharge within acceptable limits. Power capability for Earth observation passes is predicted by computing the average of the power available from solar arrays and batteries from the start of the maneuver to Z local vertical attitude through the first night period after return to the solar inertial attitude.

There were five Earth observation passes during the first half of the first manned period. During the first one, on Day 17, loads were not reduced enough to compensate for the reduced power capability in the Z local vertical pointing mode. As a result, solar observatory batteries 6, 7, 8, and 16 discharged to approximately zero percent state of usable charge, and their power conditioners were automatically turned off by the battery low voltage logic. After return to the solar inertial attitude and acquisition of sunlight these power conditioners were reconnected to the load buses. Soon after sunrise, power conditioner 3 automatically disconnected from the load buses. It did not respond to the commands to reconnect it to the buses, and subsequent analyses revealed that its regulator had failed. Power conditioner 3 was lost for the remainder of the mission. The number of power conditioners operating was reduced to 16. Solar observatory power of about 3200 watts was supplied to the laboratory loads by the transfer buses during this first Earth observation pass. Although 3200 watts is above the 2500 watts this transfer bus was designed to carry, all systems performed satisfactorily. The voltage at each bus was satisfactory and the transfer circuit capability (fuse and wire ratings) was not jeopardized. For the remaining four Earth observation passes during this time period, data taking

periods were limited to short durations and loads were reduced, so no batteries were automatically disconnected. During these passes, solar observatory batteries 5 and 6 discharged to a greater depth than the others because their solar arrays were shadowed by the solar observatory solar shield. These passes also required less power transfer because loads on the laboratory buses were reduced. The power history for the five Earth observation passes for this time period is shown in table 7-II.

Table 7-II.- Power History for the First Five Earth Observation Passes

Pass number	Day	Beta angle, degrees	Time to maneuver to Z local vertical, minutes	Time in Z local vertical orientation, minutes	Time to maneuver to solar inertial mode, minutes	Predicted power capability, watts	Average orbital load, watts	Load reduction used, percent	Maximum depth of discharge of batteries, percent
1	17	20	9	33	18	4085	3900	None	50
2	20	12	5	10	5	4534	4000	7	37
3	21	8	5	11	5	3859	4030	13	40
4	22	4	8	12	5	3940	3600	14	38
5	23	1	8	12	5	3930	3970	13	39

The crew deployed the laboratory solar array wing 1 during an extravehicular activity on Day 25. This provided an increase of approximately 2000 watts to the Saturn Workshop capability and ended the need for rigorous power management techniques. However, each daily flight plan thereafter was reviewed and each activity and time function for each of the three crewmen was entered into a computer program. The resulting vehicle power consumption obtained was compared with the predicted power capability. All operations requiring a departure from the solar inertial attitude were processed through the computer to determine the amount of power loss. Where loads approached power capability, non-essential electrical loads were turned off to provide an adequate power margin. For the remaining 14 days of the first manned period all solar inertial mode orbits had a positive power margin of 800 watts minimum. The 88 Earth observation passes completed after the workshop solar array wing was deployed still required load reduction because of the increased length of the maneuvers and the data take. Table 7-III summarizes the number and types of Earth observation passes performed during the mission and the depth of battery discharge for each type.

Table 7-III.- Summary of Skylab Mission Earth Observations

Earth observation attitude, degrees	Duration, minutes	Number of observations				Percent of battery discharge, average	
		First manned period	Second manned period	Third manned period	Mission total	Laboratory	Solar observatory
0 to 50	0 to 13	3	6	7	16	21.5	21.5
50 to 75	13 to 19.5	1	10	5	16	27.1	22.0
75 to 100	19.5 to 25.8	0	7	10	17	28.4	30.0
100 to 125	25.8 to 32	6	8	5	19	30.5	27.5
125 to 150	32 to 39.5	1	8	0	9	34.3	38.5
150 to 175	39.5 to 45.2	0	1	1	2	25.0	19.6
200 to 250	57 to 64.5	0	0	1	1	19.0	15.5
350 to 400	91 to 103	0	0	9	9	44.0	35.4
400 to 450	103 to 116	0	4	2	2	52.8	38.9
Subtotals	-	11	41	41	93	-	-

The command and service module fuel cells were deactivated on Day 32, and the Saturn Workshop electrical power system began to provide its power requirement. Its average load was approximately 1200 watts with a peak load of 2200 watts average for a 2-hour period during the entry simulations. During an extravehicular activity to retrieve film from the solar observatory cameras on Day 37, a crewman applied a mechanical shock to a prescribed location on the case of solar observatory power conditioner 15 and it resumed normal operation upon command.

During the second unmanned period, the average Skylab electrical load requirement was 3100 watts per orbit. Since the average power system capability exceeded 5000 watts for the entire period, a positive power margin of over 2000 watts existed for the entire unmanned period. The power system operated normally during this period without failure of additional subsystems or off-normal operations.

To prepare for the second crew's arrival, the thermostat setting for the docking adapter wall heaters was increased to the 21°C point by ground command on Day 75, resulting in an increased load of approximately 500 watts. At this point the average load was 3600 watts. Additional loads were added as the docking lights, transponder, and tracking lights were sequenced to support the rendezvous and docking maneuvers. The average loads of this period did not exceed 3900 watts, and since the average power capability was 5500 watts, a positive power margin of over 1600 watts was maintained. After full operations began, the total average load requirement was 4800 watts until Day 95, when the command module's fuel cells were deactivated, increasing the average load requirement to 5850 watts. The laboratory power system's regulated voltage was changed; at the high beta angle at this time and with the change in voltage, the total capability was 7000 watts, providing the necessary power margin. As the mission progressed, it was necessary to adjust the power sharing periodically to ensure that the power margin was maintained and that the battery discharge constraints were not violated.

There were 41 Earth observation passes made during the second manned period. Reevaluation of the electrical systems determined that 50 percent discharge for the laboratory batteries and 45 percent discharge for the solar observatory batteries were permissible during these maneuvers. This criterion was implemented for the Earth observation pass on Day 111, and for all subsequent Earth observation passes until Day 229. The Earth observation maneuver plans were programmed through the ground computers, and the batteries' depths of discharge were predicted. Further power management techniques were implemented only if the predicted depth of discharge exceeded the allowable value.

A failure of the charger in the solar observatory's power conditioner 5 on Day 123 again reduced power system capability, but only by approximately 100 watts. With the exception of the charger failure, the first manned period failure of solar observatory regulator 3, and the off-normal performance of power conditioner 17, all subsystems continued to operate normally during the second manned period.

Concern arose during the second manned period when the primary airlock coolant loop was shut down because of a suspected loss of coolant fluid. With only one airlock coolant loop in operation during the third unmanned period, there would be no backup system available, so a failure of this coolant loop would leave

the laboratory power conditioners without coolant flow. The batteries and electronic components in the power conditioners must be cooled when operating. Should the power conditioners lose their coolant flow, they would be shut down to ensure their availability during the third manned period. The normal procedure would be to open the battery and regulator outputs by ground command and allow the solar observatory to supply the total power until the third crew could rendezvous, dock, and resupply the coolant fluid. This operation, however, would remove power from the workshop control bus, removing command capability from the system. Disconnecting the batteries from the regulator would still leave the system operational during the daylight cycles. It was then decided that the proper way to power down in the event of a coolant flow loss was to leave the regulator output relay closed, and reduce the regulator voltage, so that the solar observatory would provide all of the power to the vehicle, effectively reducing the laboratory power output to zero. This would allow power to flow to the control bus through the regulator from the solar observatory. Figure 7-7 shows the path for this power flow. Because the regulator voltage can only be adjusted manually, it was required that this be done immediately before the crew's departure. This would have placed the entire electrical load on the solar observatory for the entire unmanned period to follow, which was undesirable. Therefore, the Saturn Workshop was changed from the normal configuration before reduction of the laboratory voltage by opening the transfer relays. The resultant 27 volts was sufficient to power the loads, and the transfer relays were left in the open position, with each system operating independently. Should the coolant loop fail, the transfer relays would be closed and the system would be in the contingency operating configuration. Fortunately, the coolant system operated satisfactorily during the third unmanned period, and the transfer relay was left open until after the arrival of the third crew.

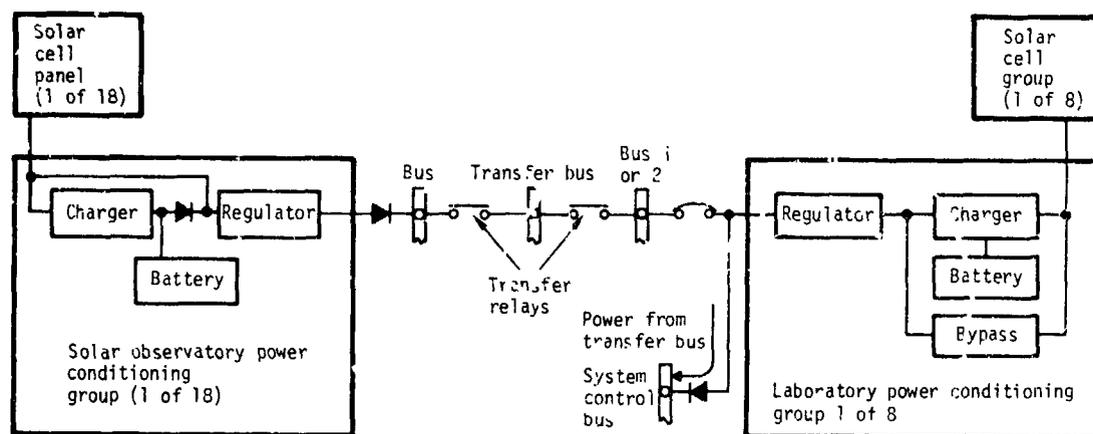


Figure 7-7.- Solar observatory power supplied to laboratory control bus.

The laboratory electrical power system operated normally during the entire third unmanned period. The average laboratory electrical load during this period was 1100 watts and the capability of the system varied from a minimum of 2900 watts to a maximum of 3600 watts. The resulting laboratory battery discharge for the 1100-watt load over the range of beta angles encountered during the unmanned period varied from 6 to 8 percent. The solar observatory electrical power system operated normally, with the exception of power conditioner 17. Because of the off-normal operation of this subsystem, its contribution to the total output was 80 percent less than that of the remaining 15 power conditioners. On Day 151

power conditioner 17 was removed from the load bus for a period of 20 hours. After it was returned to the load bus it began to function properly, and for the remainder of this period its contribution to the total power capability was equal to that of the other 15 active power conditioners. The average load requirement was 2000 watts, and the average system capability varied from a minimum of 3800 watts to a maximum of 4900 watts. The resulting battery discharge for the 2000-watt load over the range of beta angles encountered during the unmanned period varied from 12 to 14 percent.

One day prior to the launch of the third crew, the thermostat setting for the docking adapter wall heaters was once more increased to the 21°C setting, which resulted in an increased load on the laboratory system of 500 watts to a total load average of 1600 watts. Additional loads were the tracking lights, transponder, and docking lights to support the rendezvous and docking operations. The average of the peak loads on the laboratory system for this period was 1900 watts; the average load on the solar observatory system remained at 2000 watts. Because of the high beta angle, the power capability for both systems was the highest for the entire unmanned period at this time. A large positive power margin was still maintained for each system.

When the Saturn Workshop activation began, one of the first tasks accomplished was to parallel the electrical power systems and adjust the laboratory open circuit voltage to 29.1 volts for the first activation day. It was increased to 29.3 volts for the remainder of the activation period. The power capability of the two systems operating in parallel at the 29.1-volt setting was 8000 watts. The adjustment to 29.3 volts caused the combined capability to decrease to 7900 watts. After full activation the average load was 4800 watts when the crew was awake and 4200 watts when the crew was asleep. With the 7900-watt capability for this period, a power margin of 3100 watts existed. The command module fuel cells were deactivated on Day 206, and the load was switched to the Saturn Workshop power system. The total Skylab load increased to 5800 watts average when the crew was awake and 5200 watts average when the crew was asleep. The 6200-watt power system capability on Day 206 provided a minimum power margin of 400 watts.

During the Earth observation orientation the discharge limit on the laboratory and solar observatory power systems was relaxed, to permit deep discharges for this limited number of cycles. For the first 43 days of the third manned period the constraint on the solar observatory batteries permitted a maximum of 9 amp-hr (45 percent) to be removed; similarly, the laboratory battery discharge constraint was 16 amp-hr maximum (48.5 percent).

On Day 229 a battery capacity test was conducted on solar observatory batteries 10 and 18. Since the measured capacity during this test was less than the predicted value, the solar observatory constraint was changed to 8 amp-hr (40 percent). Since this decrease in stored energy available from the system restricted to a degree the types of Earth observation passes permissible, on Day 243 the laboratory criterion was relaxed to permit a maximum of 20 amp-hr (60.6 percent) to be removed from the laboratory batteries.

An Earth observation pass was performed on each of two successive orbits on Day 246, which resulted in a violation of the 8 amp-hr constraint on solar observatory battery 11. The actual discharge was 8.23 amp-hr. Since the excursion

above 8 amp-hr was small and at a relatively low discharge rate, power conditioner 11 did not automatically disconnect from the system. Following the return to the solar inertial attitude, enough energy was available to completely recharge the battery during the following orbit. Therefore, the violation of the constraint did not adversely affect the power system performance and was not considered off-normal operation.

During the third manned period, one of the major experiment objectives was to obtain data on Comet Kohoutek. To obtain the proper angle for comet observation, it was necessary to maneuver away from the solar inertial attitude. The percent of discharge for all the batteries was computed for each pass to ensure that the power system's integrity was protected. However, most of the passes centered around orbital midnight, so the resulting discharge levels approximated that of a normal solar inertial night period. Two comet observation passes and one Earth observation pass required additional capability to ensure that the 8 amp-hr maximum discharge criterion was not violated. Power conditioner 5, which had a charger problem, was managed by ground control to provide the additional capability needed.

Many of the changes in battery discharge levels during the mission were related to the adjustment of the regulator bus open circuit voltage, but in addition the discharge also changed with the beta angle except when it was greater than 69.5 degrees and there was continuous sunlight. Figure 7-8 shows the average percent of discharge at the solar inertial attitude for both the systems and the relationship of discharge level to the beta angle for the mission.

Figure 7-9 shows the performance history of the Saturn Workshop electrical power system for the mission period, including both the average power loads and the system capability. The reduction in loads during the unmanned periods was due to the absence of the crew and the reduced operation of the integrated experiments. The total experiment loads could reach as high as 1500 watts during manned operation; however, planned operation required approximately 500 watts of power. During the unmanned period, some experiments were operational and others required thermal protection. Approximately 200 watts of power was used for this purpose.

## 7.2 LABORATORY POWER SYSTEM

The laboratory electrical power system was to have derived power from two solar array wings. A wing is made up of three sections arranged to provide eight isolated power groups. The eight power groups on each wing are normally paired in parallel and connected to eight power conditioners. The power conditioners supply the two main buses that supply power to the electrical equipment in the laboratory. The laboratory electrical power system normally operates in parallel with the solar observatory electrical system; however, independent operation is possible by opening transfer bus circuit breakers. The amount of power supplied by each of the two electrical systems is controlled by adjusting regulators that control voltages of the two laboratory regulated buses. The voltage is adjusted to some value relative to the voltage of the solar observatory power so that the ratio of load demand to system capability is nearly equal for the two electrical power systems.

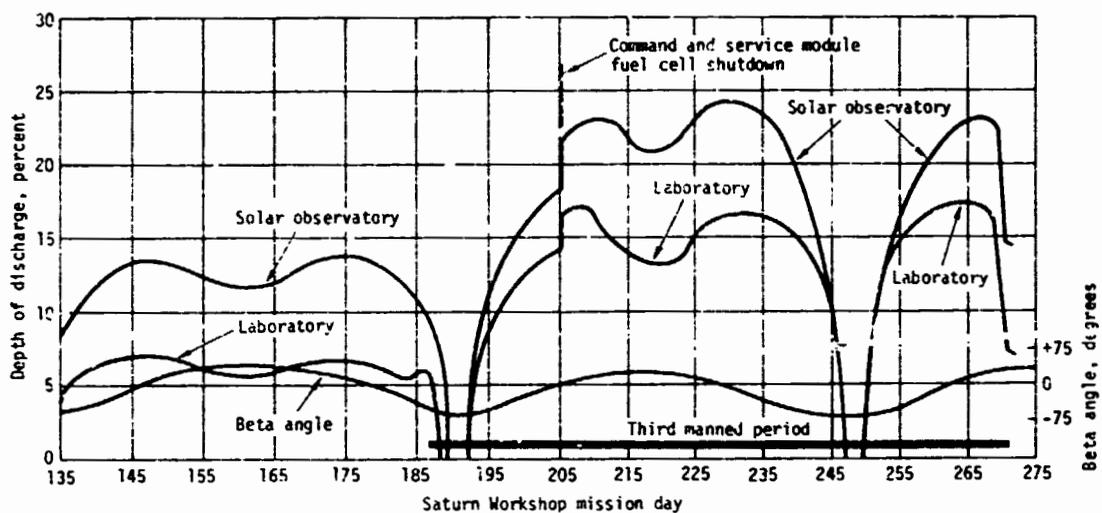
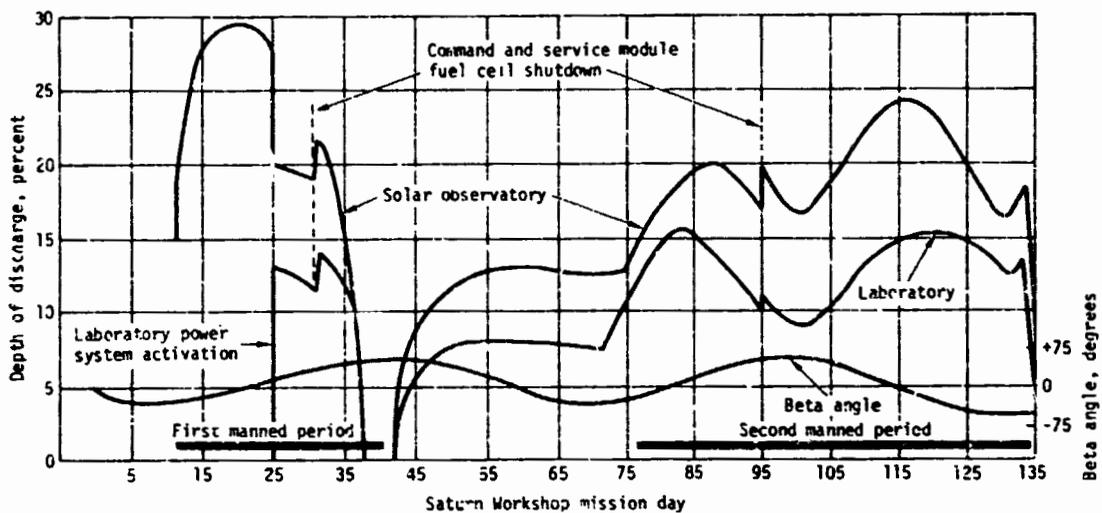


Figure 7-8.- Average battery discharge history at solar inertial attitude.

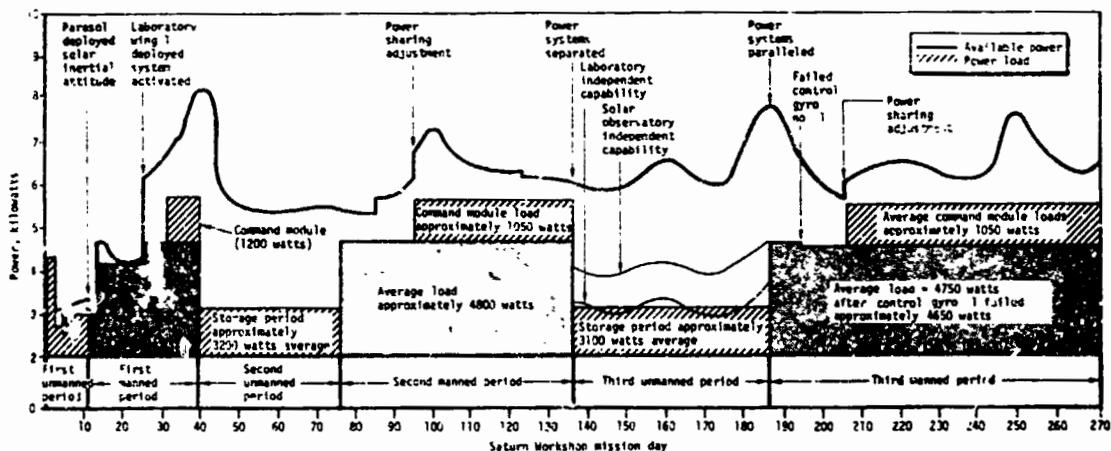


Figure 7-9.- Electrical power capability and average load history.

Because of the loss of one solar array wing and the failure of the other to deploy fully, the power conditioners were disconnected from the load buses approximately 2 hours after the Saturn Workshop launch, to prevent complete discharge of the batteries. The laboratory solar array wing was approximately 10 percent deployed and provided 100 to 180 watts, depending upon attitude. This limited power was used to recharge four of the eight batteries at a low charging rate. The laboratory electrical power distribution networks and controls were used during this period to achieve near-normal operation with the solar observatory system supplying the electrical power.

The crew released the partially deployed array on Day 25. The laboratory electrical power system performed according to predictions throughout the remainder of the mission. No contingency operations were performed, and no unplanned switching operations were required. The regulator bus voltage control potentiometers were adjusted several times to optimize load sharing between the two power systems according to their respective power capabilities and load requirements. Load sharing among the eight power conditioners was stable and was performed as predicted.

Actual power use during solar inertial attitudes varied from 1600 to 3500 watts with average battery discharges of 0 to 17 percent of full capacity per orbit. The maximum depth of discharge of 57 percent occurred after an Earth observation experiment orbit on Day 256.

The system performed well throughout the mission, and no failures of equipment were noted. All required operations associated with activation, deactivation, paralleling, and Earth observations were successfully completed. Several voltage regulator fine adjustments were made to optimize power capability. All system parameter monitors functioned properly.

#### 7.2.1 Solar Array

The workshop solar array wing consists of an open box type beam and three wing sections. Each wing section consists of 10 identical solar cell panels for a total of 30 panels for the wing. Two additional panels are included in each wing section to provide spacing between the active panels and the beam fairing; one is a truss panel and the other an inactive panel. Figure 7-10 shows the physical arrangement of the solar wing components and their physical characteristics.

Each active panel consists of 4 separate and isolated solar cell modules for a total of 120 modules for the wing. These modules are bused together into 8 groups of 15 modules each. These groups together with power conditioners form eight individual power sources. Since the eight solar array groups in each wing are paralleled, the loss of solar array wing 2 resulted in a 50 percent reduction in current at no change in voltage, causing only a reduced load capability. The wing which was lost had the same arrangement shown for wing 1, so the modules' power conditioners 1, 2, 3, and 4 were outboard from the Saturn Workshop, opposite to the inboard arrangement of wing 1. This eliminated the possibility of the Saturn Workshop's shadowing both halves of a power group during non-solar-inertial attitudes. Without this wing, power groups 1 and 3, because of shadowing, had the lowest power outputs of the groups during Earth observations.

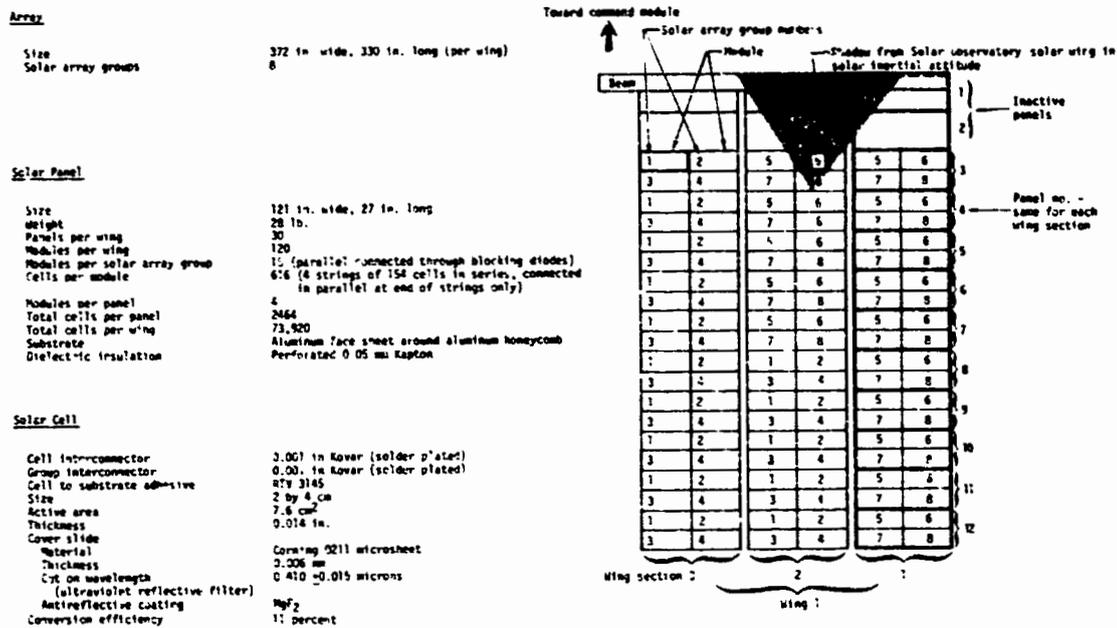


Figure 7-10.- Workshop solar array wing configuration.

**Thermal Characteristics.**- The operating temperature of the solar cells is determined from the outputs of 10 temperature transducers mounted on the solar array wing. The temperature transducers' outputs vary in a cycle with each orbit. Figure 7-11 shows solar array temperature profiles for orbits at beta angles of 0, 30, and 60 degrees.

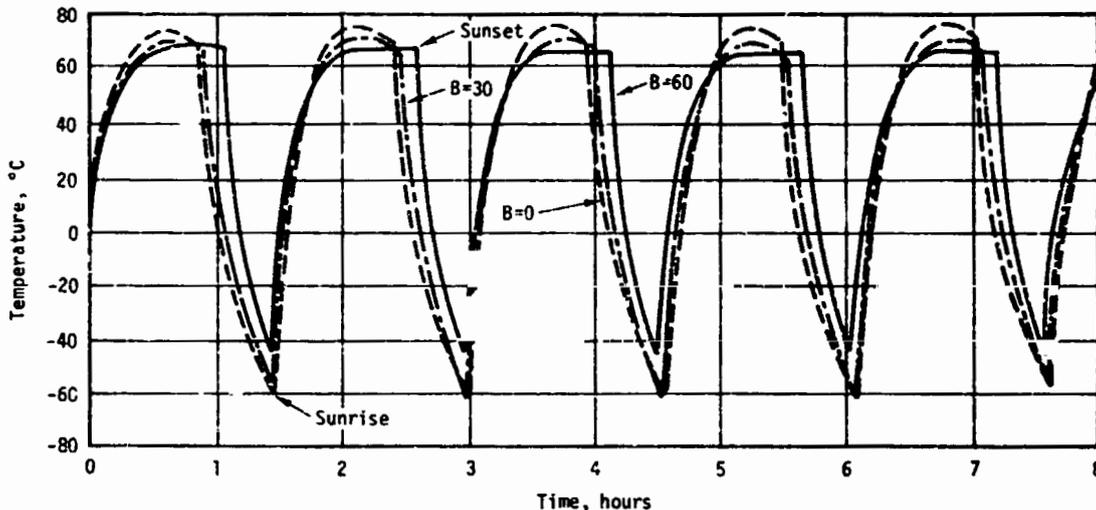


Figure 7-11.- Temperature profile for workshop solar array wing at various beta angles.

Actual temperature profiles were similar to premission predictions, but loss of the meteoroid shield produced some differences. The meteoroid shield in the vicinity of solar array wing 1 was painted black and had a low reflectivity. The exposure of the highly reflective gold surface of the workshop resulted in increased reflection of the direct solar radiation and the reflected light and

direct thermal radiation from the Earth. This additional reflected energy raised temperatures on the wing section closest to the workshop, but had little effect on the outer wing section.

The lower predicted temperature at orbital noon was based on the solar array's operating at peak power while in sunlight. Peak power operation actually ends when the batteries approach full charge, generally in the first 20 minutes of sunlight. When the array operates below peak power, efficiency drops and the array's temperature rises.

**Power Output.**- The original two-wing solar array subsystem was to deliver an average available power of 10.5 kilowatts, within a voltage range of 51 to 125 vdc, integrated over the sunlit portion of the orbit. Based on a prelaunch prediction of 8.3 percent performance degradation for the mission, a minimum power capability of 11.5 kilowatts was required at the beginning of the mission to provide this required power at the end of the mission. With the loss of wing 2, this power capability was reduced to one-half of the predicted values. Figure 7-12 shows the performance of solar array wing 1 compared to these requirements. The voltage and current outputs of the eight solar array groups

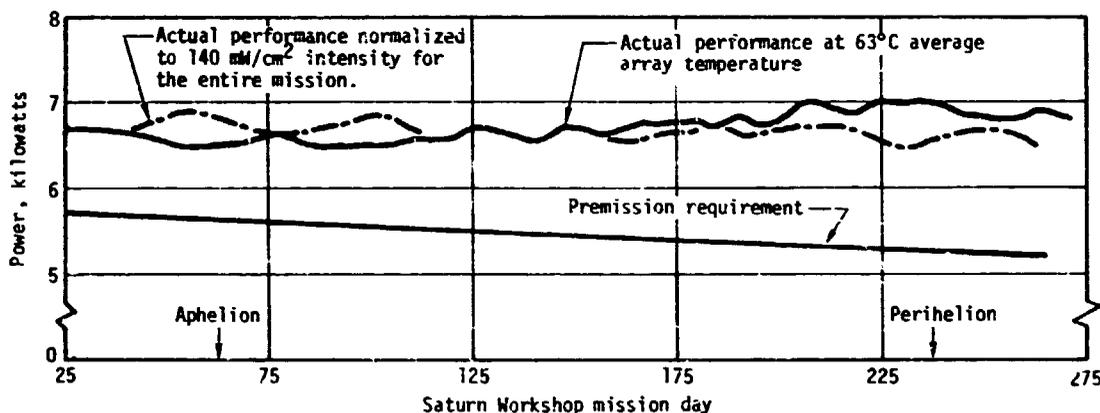


Figure 7-12.- Performance of solar array wing.

are similar except where modules are shadowed by the solar observatory solar array. Solar array groups 5 and 8 each have one module shadowed; group 6 has two modules in the shadow. Figure 7-13 shows the voltage and current outputs of these groups during a typical orbit.

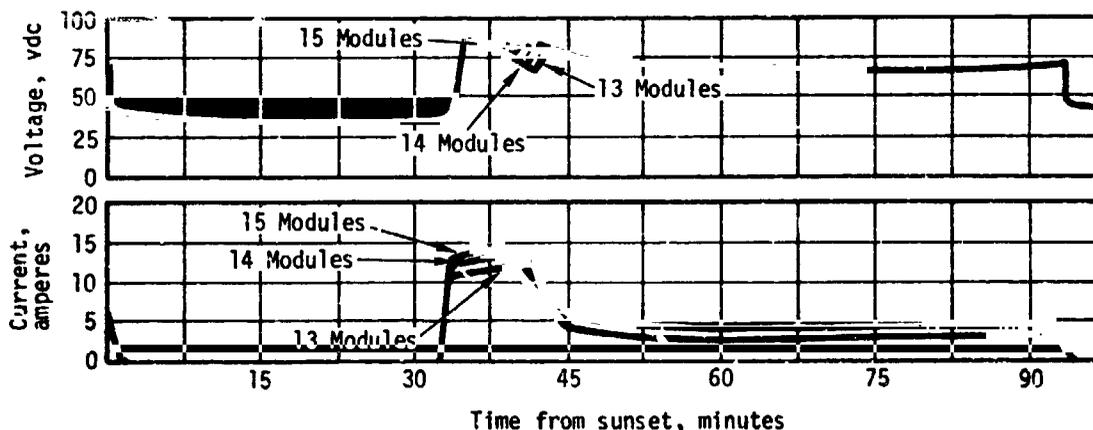


Figure 7-13.- Typical workshop solar array group output for one orbit.

As the solar array went into shadow, the current dropped to zero, and the voltage dropped to the power conditioner battery voltage. When the array came into the sunlight it was cold, and the voltages were at their peak values; the voltages decreased as the array warmed up. The current was high because of the increased loads of the batteries recharging. When the batteries approached full charge the charge rate decreased, resulting in a drop in the current and a rise in voltage. After the batteries were fully charged the current remained nearly constant at the lower values shown, and the voltage continued to vary according to the temperature. The slight rise in voltage before the end of the sunlight portion of the orbit corresponded to the small decrease in temperature that occurred when the incidence angle of the back of the solar array surface to the Earth's surface increased.

One abnormal condition was noted for solar array group 4. Onboard and ground equipment displays consistently indicated a lesser current output from group 4 than from the other groups. Evaluation of the other power conditioner 4 measurements verified that this group was operating with the same capabilities as the others. The loss of solar array wing 2 probably allowed a solar array group 4 return wire to make contact with the vehicle surface, causing a current path around the current monitoring shunt devices. Regulator bus 1 current indicators, which are a summation of the current of the power groups feeding the bus, were also low by the same amount as solar array group 4. Data from these two items were corrected by adding a value equal to the difference between them and the average current readings of the other groups. Low readings continued, but the workaround procedure was satisfactory for evaluation purposes.

The average power output for solar array wing 1 at the end of the mission was 6970 watts. This apparent high power was due in part to the occurrence of the maximum solar flux intensity because the Earth was then at perihelion. Also, the following circumstances contributed to the higher than predicted output:

- a. The average solar cell output was higher than expected. (256 milliamperes versus 248 milliamperes).
- b. Wiring sizes were chosen assuming worst-case temperatures, which resulted in less voltage drop than predicted.
- c. The assumption of an 8-degree orientation error existing continuously between the Sun and the arrays was overly conservative.
- d. Shadow pattern analysis had assumed that 17 out of 240 modules would be shadowed for periods up to full orbit under thruster attitude control with a 5-degree deadband. The deadband was changed to 3 degrees prior to launch. Moreover, use of thruster control was minimal.
- e. Power calculations were based on worst-case values of heat flux for entire orbits. This was done because the random behavior of infrared radiation and albedo of the Earth are not well known.

#### 7.2.2 Power Conditioners

Major components of each power conditioner are a charger, battery, and voltage regulator.

Chargers.- The battery charger receives power from the solar array and supplies it to the bus regulator to satisfy load demands and to charge the battery. After load demands are met, the remaining power is delivered to the battery. A peak power tracker unit restricts the charger output so that the solar array power requirement does not exceed the maximum power point, thereby preventing overloading of the arrays. An ampere-hour meter controls battery charging by measuring the amount of current supplied by the battery and ensures that a like amount is replaced.

The battery chargers performed satisfactorily both before and after the deployment of solar array wing 1. The battery chargers in power conditioners 5, 6, and 7 operated with dual low power solar array inputs to charge their respective batteries to 100 percent charge. Solar array currents during the charging of these batteries were between 0.4 and 1.2 amperes for power conditioners 5 through 8. These current levels are well below the desired range of operation for the battery chargers.

The other four batteries could not be charged because the array power available, even from dual solar array group combinations, was insufficient to operate the battery chargers. Another result of the low solar array power was that battery chargers 1, 3, 4, and 8, and possibly the other battery chargers, experienced an oscillating input caused by the repetitive collapse and recovery of the solar array output characteristic. The array voltage would rise to the point at which the battery charger bias circuits would turn on. The current drawn by the bias circuits, however, would pull down the solar array voltage to such a level that, because of the low solar array power, the circuits would turn off again. At this point the array voltage would recover to its original level, and the cycle would repeat. Analysis of the battery charger circuits indicated that this condition should not cause any problems. As a safety factor, however, the charger switch was placed in the bypass position, so that the solar array output was removed from the battery charger input.

Each battery charger conditioned its associated solar array group input so that peak power was extracted upon demand during initial battery charging, battery voltage was limited as determined by battery temperature during the voltage limit charge mode, and battery current was regulated when the battery-charger-controlling ampere-hour meter indicated a 100 percent battery state of charge. Figure 7-14 illustrates the typical operation of a power conditioner for one discharge-charge cycle after the laboratory solar array wing deployment.

Peak Power Tracking.- Peak power tracking is experienced from the beginning of each sunlight period until the battery is fully charged. Available solar array power is maximum at sunrise, and gradually decreases as the solar array group temperature increases. The peak power tracking portion of the charger input power curve is shown in figure 7-14. The charger peak power tracker extracted maximum power from the solar array group immediately upon sunrise and then decreased its demand as the available solar array group power decreased. As shown in the figure, the peak power tracker closely followed the characteristic solar array profile until the battery charge voltage limit mode was reached. At this time, the charger input power decreased with the reduction of battery charge current demand. This device performed satisfactorily throughout the entire mission.

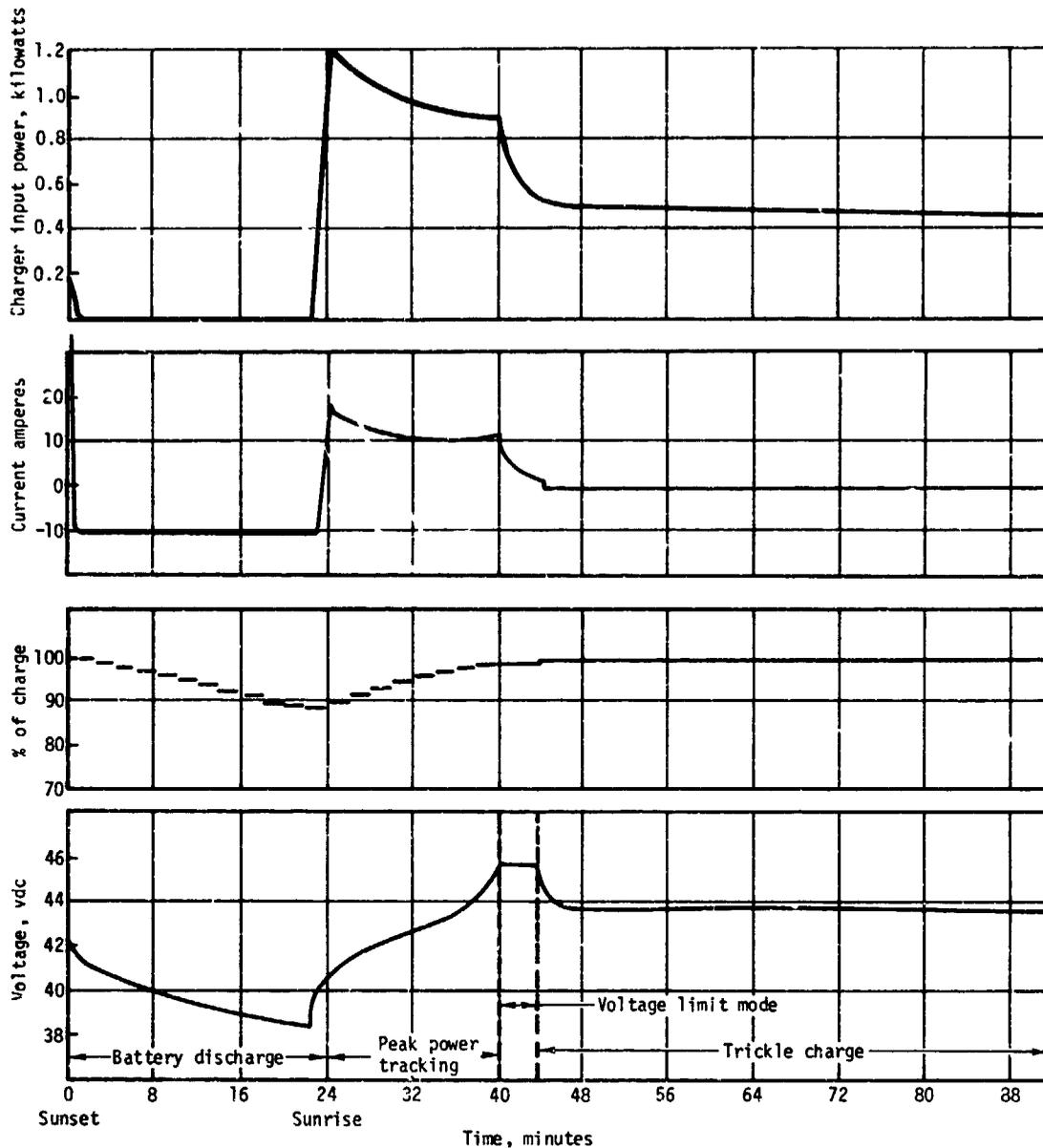


Figure 7-14.- Typical discharge-charge cycle operation for a power conditioner.

**Battery Voltage and Current Regulation.**- Battery charging is designed so that the battery voltage will not exceed a limiting value imposed by battery temperature. Data showed that the battery charger limited the battery under charge to the correct value for the corresponding battery top-of-cell temperatures. Battery temperatures throughout the mission varied from  $-1.0$  to  $+4.5^{\circ}\text{C}$ , well within the predicted ranges.

When the controlling ampere-hour meter indicated that the battery had returned to 100 percent of charge, the battery current was regulated to  $0.75 \pm 0.5$  ampere. The battery current curve in figure 7-14 shows the drop to the trickle charge level at the time that the controlling ampere-hour meter reached 100

percent charge. The current then remained stable at 0.9 ampere throughout the trickle charge region. This operation was typical for all eight power conditioners throughout the entire mission.

Ampere-Hour Meter Control.- The ampere-hour meter tracks the battery discharge-charge profile in 1 percent steps. Accuracy of the readings is improved by including in the integration of battery charge current a temperature compensation factor, which corresponds to the battery temperature. Figure 7-14 shows the typical relationship between the ampere-hour meter charge indication and the battery current. The meter accurately registered battery discharge and charge. Upon reaching 100 percent, the battery charger control circuitry was switched to trickle charge. The meter output remained at 100 percent until battery discharge began at the next sunset. The calculated percent of charge using battery current and temperature data compared closely with values obtained by the ampere-hour meter readouts.

A downward drift trend was noted on several of the primary (controlling) ampere-hour meter indications before and during the second manned period. In some of these instances the secondary ampere-hour meter indications showed a more pronounced downward drift than their associated primary ampere-hour indications. Real-time analysis of other battery parameters--voltage, current, and temperature--indicated that the batteries in question were being fully charged and that the drift was associated with ampere-hour meter operation only. Further analysis of flight data indicated that for the minimum power margins encountered during these periods, the return factor of the ampere-hour meter was not being satisfied even though the battery was actually being fully charged. The erroneous ampere-hour meter indications had no effect on system operation. Following the minimum capability periods, the state of charge indications recovered to normal levels and displayed the actual battery status.

Batteries.- Each battery has 30 series-connected, nickel-cadmium, sealed cells. The batteries operate between 30 and 48 vdc and have a 33 amp-hr rating. Thermistors in the batteries provide temperature sensing for telemetry, ampere-hour meter compensation, charge control, and protection against excessive temperatures. Active cold plates regulate overall case temperature.

The eight laboratory electrical power system batteries provided power during the launch phase. The batteries were then turned off at approximately 2 hours after liftoff when it was determined that solar power was not available. Batteries at this time ranged from 64 to 68 percent of full charge. The batteries were turned off to retain their stored capability as backup power sources for low power capability periods, such as during Earth observation passes, and also to retain maximum flexibility in managing the batteries as the mission progressed.

The batteries were turned on on Day 12 in preparation for the activity to deploy solar array wing 1. They only provided the electrical system control power because all of the regulator output power relays were in the off position. The deployment attempt was unsuccessful and all batteries were subsequently turned off after approximately 8 hours of operation. The percent of charge for batteries 1 through 4 at this time ranged from 48 to 53 percent. Batteries 1 through 4 remained off until Day 25, when they were turned on in preparation for the second attempt to achieve solar array wing 1 deployment. Batteries 5 through 8

were cycled on and off at various times for trouble-shooting purposes and attempted charging by the partially deployed wing. On Day 22, batteries 5, 6, and 7 were recharged to 100 percent. Battery 8 could not be recharged because its available solar array power was insufficient to operate the battery charger.

The initial 24-day period, during most of which all eight batteries were turned off in a partially discharged state, constituted an abnormal storage period for the batteries. Recommended storage is either discharged at an 18 amperes rate to a potential of 30 volts for long storage periods or fully charged with weekly boost charge periods. Although no special operations were used to condition the batteries, they responded as expected when solar array power became available to charge them.

Table 7-IV shows the indicated percent of charge of the batteries just before and one orbit after solar array beam deployment. The reading for battery 8 in the table is abnormally low. This was a result of the ampere-hour integration being inadvertently reset to zero on Day 14, at which time it was reading 45 percent charged. The ampere-hour meters for battery 8 were synchronized with the actual battery percent of charge on Day 29 and operated normally thereafter.

Table 7-IV.- Laboratory Batteries' Percent of Charge

Day	Time, Gmt, hr:min	State of charge, percent							
		Battery 1	Battery 2	Battery 3	Battery 4	Battery 5	Battery 6	Battery 7	Battery 8
158	17:00	45.8	45.8	50.7	48.3	96.2	99.0	95.5	0
156	20:07	55.4	54.1	62.7	56.2	99.8	100	100	21.4

Battery cyclic performance from the time of solar array deployment until the first command and service module undocked was good. In the course of the first manned period, 219 battery cycles were accumulated. Figure 7-14 shows a representative cycle profile of battery parameters. The charge voltage limitation mode occurring at this time resulted in some available power not being used, but the charge voltage on the battery was maintained at the proper level. This condition continued until cyclic battery inefficiencies were satisfied by returning more ampere-hours than were discharged (overcharge), at which time the charge automatically reverted to a maintenance trickle charge. The trickle charge continued until the next discharge period.

The depth of discharge most commonly experienced during the first manned period was 12 to 14 percent. Up to 30 percent discharge occurred during high activity periods or at vehicle attitudes other than solar inertial. A curve for a 16- to 18-ampere discharge rate was obtained during performance of a battery capacity test on Day 106. For this test, the regulator output voltage was adjusted to increase the load on battery 8, and the solar array input was disconnected from the power conditioner to maintain continuous battery discharge during the test.

Besides the test on battery 8, a capacity test was also performed on battery 6 on Day 105. Capacity of the batteries had been determined in ground tests by measuring the ampere-hours extracted at an 18-ampere discharge rate to an end voltage of 30 volts. The inflight discharge procedure deviated from the ground

practice in that the crew terminated the discharge when they detected a terminal voltage of 33 volts. The charger ampere-hour meter state-of-charge indication was used to measure the obtained capacities during these discharges. The discharge characteristic exhibited at acceptance testing had in both of these tests changed to one in which an initial voltage plateau developed at a lower level than the single plateau of the acceptance characteristic. The final few data points before the termination of the inflight discharges indicated the development of a second lower plateau, which was compatible with ground test experience.

Composite battery discharge data for the operating period from Day 76 through Day 135 were compared with the data from the first manned period. This indicated a detectable recession of the initial discharge characteristic plateau. This correlated with the previous inflight capacity discharge characteristics and with ground test results. During this period, some ampere-hour meters' readouts drifted from the actual state of charge of the batteries. A comparison was made of all the battery discharge terminal voltages for the same points in time during the ampere-hour meter drift period. Analysis showed comparable voltage levels for all the batteries. This consistency, with the lack of a voltage degradation trend, indicated that all the batteries were being fully charged, despite the ampere-hour meter indications.

The batteries had accumulated 1683 discharge-charge cycles at the time the second crew departed on Day 135. The depth of discharge range most commonly experienced during the second manned period was 13 to 16 percent. Forty-one Earth observation passes were performed during this period. Battery depths of discharge were generally greater during these times than during normal solar inertial operation. The maximum depth of discharge experienced occurred during the final Earth observation pass when individual discharge depths ranged from 36 to 42.7 percent.

Laboratory batteries are actively cooled. Parallel coolant flow at controlled temperatures is provided to coldplates for batteries 3, 4, 7, and 8. The coolant from these coldplates flows to the coldplates for batteries 1, 2, 5, and 6, respectively, in such a manner that for each pair, the heat picked up from the first battery increases the coolant inlet temperature at the second battery. On Day 104, a coolant loop system operational change decreased the coolant mass flow by approximately 50 percent. The effects were detectable by an approximately 1°C increase in the operating temperatures of batteries 1, 2, 5, and 6. Changes in the temperatures of batteries 3, 4, 7, and 8 were too small to be detected in the telemetry scatter. Other than this detected increase, the indicated top-of-cell battery temperatures were comparable to those experienced during the first manned period.

Contingency planning called for discontinuing power conditioning during the third unmanned period in the event of coolant loop depletion. However, execution of this plan proved unnecessary, and the batteries cycled throughout the entire unmanned period. At the beginning of the third manned period, the batteries had accumulated 2486 cycles. The cycle depths, which averaged approximately 7 percent during this period, were less than those of the second unmanned period because of the independent operation of the two power systems and the load configuration used for the contingency plan.

The battery discharge-charge cycle accumulation at the time the third crew departed on Day 271 was 3790 cycles. The discharge depths experienced during the

solar oriented periods ranged from 12 to 19 percent. Discharge depths near 50 percent were common for the non-solar-inertial experiment orientations, with the maximum depth reaching 57 percent. Non-solar-oriented attitudes were established 110 times in the course of the mission for Earth observations and Comet Kohoutek observations. Failure of a control gyro on Day 194 resulted in more non-solar-oriented attitude time than normally would have been required to accomplish the desired observations. Battery performance was uniform and reliable during the period. The batteries' ability to sustain the heavy depths of discharge dependably contributed to the high success level.

Capacity discharges were performed on battery 6 at the beginning, in the middle, and at the end of the third manned period. The first two discharges were performed according to the procedure that had been used in the second manned period, while the third discharge was continued until the battery terminal voltage reached 30 volts. A consistent pattern of battery output voltage regulation degradation with increasing cycle accumulation was seen when the capacity discharge information from the third manned period was compared with earlier data.

As part of the third crew's closeout of the Saturn Workshop, the electrical power system was configured for capacity testing of all batteries after the crew departure. This configuration allowed ground selection of any one of the eight batteries for discharge, established discharge rates near the ground test level, permitted continuous discharge of the selected battery to a 30-volt completion, and provided a self-limitation of battery discharge as the battery terminal voltage approached 29 volts. The self-limitation feature was desirable because ground station coverage could not be ensured at every critical discharge time. The flexibility of the control capability aided greatly in accomplishing the test objectives.

All eight batteries were discharged to 30 volts during the end-of-mission test period. In addition, batteries 6 and 8 received a second full capacity discharge during this period. Three distinct discharge profiles were found to exist. Figure 7-15 depicts the discharge characteristics of all the batteries

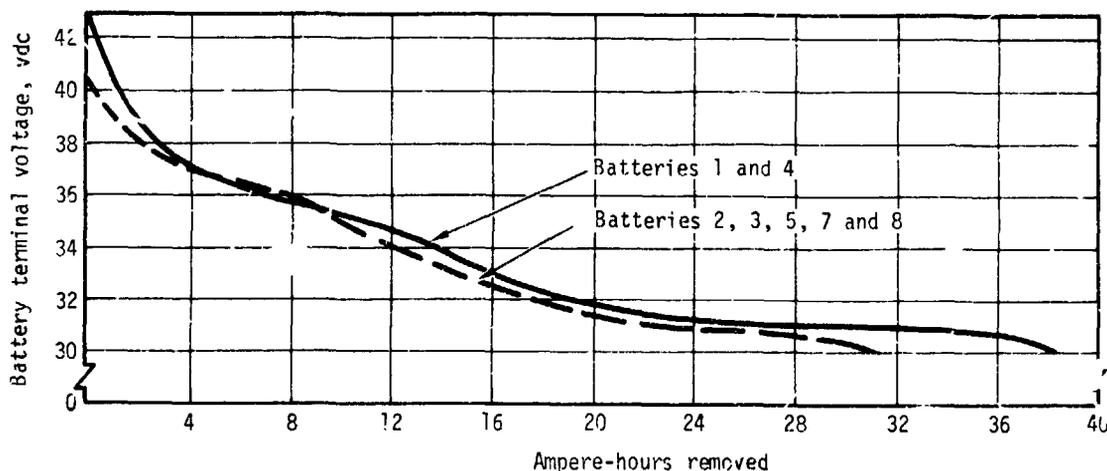


Figure 7-15.- Discharge profiles at the 380C cycle.

except battery 6. The discharge characteristics of battery 6, which was discharged to 30 volts shortly before the crew departed, are shown in figure 7-16. These figures are consistent with previous ground test experience on units with

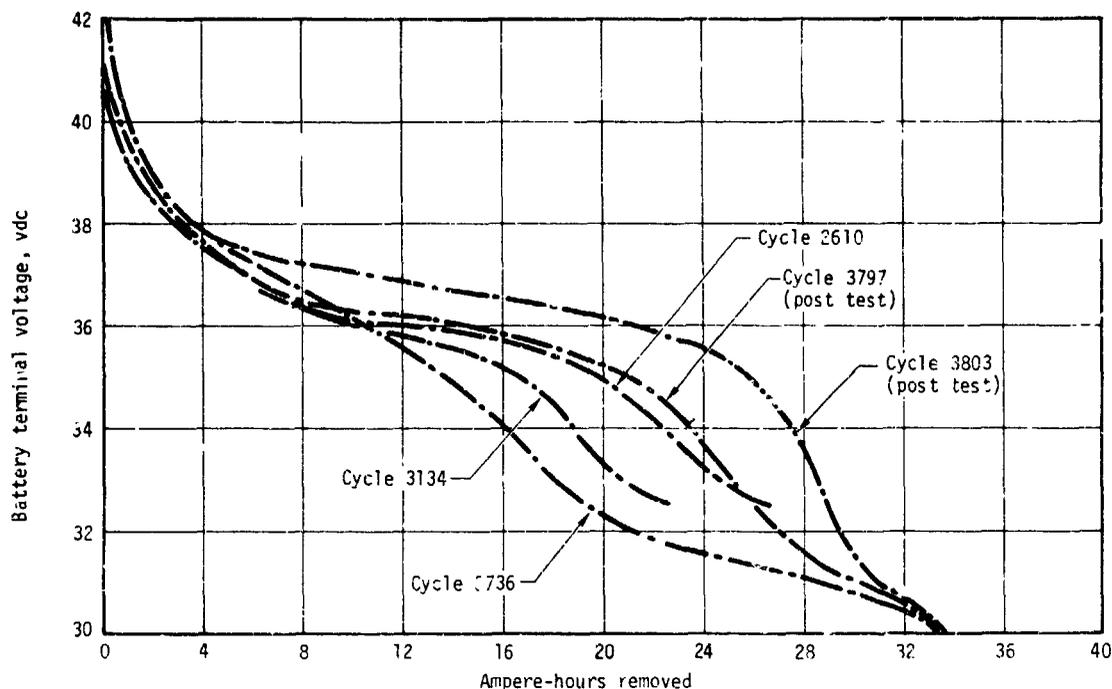


Figure 7-16.- Battery 6 inflight capacity discharges.

similar history, except for the duration of the second voltage plateau, which begins at about 16 amp-hr. One possible factor contributing to this difference is the length of time the various batteries were in the vehicle before launch. Batteries 1 and 4 were in the vehicle 22 days before launch, while the rest were installed 23 days before launch. The second voltage plateau for batteries 1 and 4 was longer, and resulted in greater ampere-hour capacity. A comparison of the profiles in figures 7-15 and 7-16 indicates that battery 6 had a slightly better performance characteristic than other batteries of similar history. Full capacity discharges on the subsequent discharge profiles can be seen in figure 7-16 by comparing the 3736 cycle to the 3797 cycle and finally to the 3803 cycle. This same phenomenon was present in the end-of-mission capacity data for battery 8.

Bus Voltage Regulators.- The charger normally inputs power to the regulator; however, a bypass switch allows the solar array power to feed directly to the regulator in the case of a charger malfunction. A potentiometer simultaneously adjusts the output of all regulators which are tied to the same bus. This bus voltage adjustment is made to share bus loads properly. Fine adjustment (trim) potentiometers provide load sharing by the individual regulators.

Before launch the individual regulator potentiometers were set to a value that caused the batteries to discharge at a uniform rate. This was done to compensate for the variations in battery cells, differences in the individual circuit and component resistances, and differences in regulator efficiencies. The regulators operated satisfactorily during all periods of operation from launch through the end of the first manned period. Regulated bus voltages were maintained within 0 to 0.75 volt for all input voltage levels and loads.

The effectiveness of the individual regulators in sharing the loads equally is shown in table 7-V, which tabulates the power provided by each power conditioner

Table 7-V.-- Battery-Regulator Performance for One Orbital Night

Regulator bus number	Battery	Start of discharge		End of discharge		Minimum percent state of charge
		Voltage, dc	Current, amperes	Voltage, dc	Current, amperes	
1	1	41.78	8.74	38.32	9.44	88.5
1	2	41.79	8.66	38.23	9.37	88.1
1	3	41.99	8.59	38.23	9.38	88.5
1	4	42.08	8.68	38.23	9.39	89
2	5	41.57	8.97	38.02	10.15	87.5
2	6	41.68	9.39	38.02	10.18	86.3
2	7	41.88	9.39	37.83	10.97	87.4
-	8	41.78	9.53	37.83	11.27	86.3

during the dark portion of an orbit. As the battery voltage decreased near the end of discharge, the constant power demand of the regulators caused the discharge current to increase. Batteries supplying the input power to these regulators exhibited a uniformity of voltage-current performance which made adjustment of fine trim potentiometers unnecessary during the first manned period. Several adjustments of the fine trim potentiometers were made during the second manned period for the purpose of regulating the load demand with respect to the available ar av power. No fine trim potentiometer adjustments were made necessary, however, by power module failure, voltage regulation drift, or instability.

The bus voltage potentiometers were adjusted by the crew several times during the mission to change the load sharing ratios between the laboratory and solar observatory electrical power systems. Open circuit voltage settings were calculated from computer simulation data for various load requirements. Performance evaluations of actual load sharing versus regulator voltage settings verified the validity of these computations.

The voltage regulator contains five power modules, which are redundant to meet the high reliability requirements. Each module operates successively as the output current demand is increased by a 13-ampere increment. During Day 37 and again on Day 125, the regulator bus load was great enough (approximately 15 amperes per group) to require two power modules in each regulator to operate. These two power modules operated satisfactorily. An apparent short on the solar observatory television bus 2 on Day 83 resulted in a load of more than 200 amperes on regulator bus 2. This meant that four and possibly five of the modules in each voltage regulator did operate for approximately 3 seconds. Voltage regulator temperatures, which ranged from -100 to +15°C, indicated normal regulator operation.

### 7.2.3 Power Distribution

Distribution Networks.— The laboratory power distribution system provides electrical power to the docking adapter and workshop loads and, when required, to the command and service module loads. Transfer of power to the command and service module requires that an umbilical cable be connected through the docking adapter-command module hatch. Transfer buses also supply power to or accept power from the solar observatory power system in parallel operation. Figure 7-17 is a diagram of the laboratory electrical power distribution system.

Laboratory power is distributed by a two-wire system and a series of interconnecting buses, switches, diodes, and sensors. Two redundant buses in the command and service module distribute power to its components. A single-point ground on the command and service module structure is used to eliminate ground

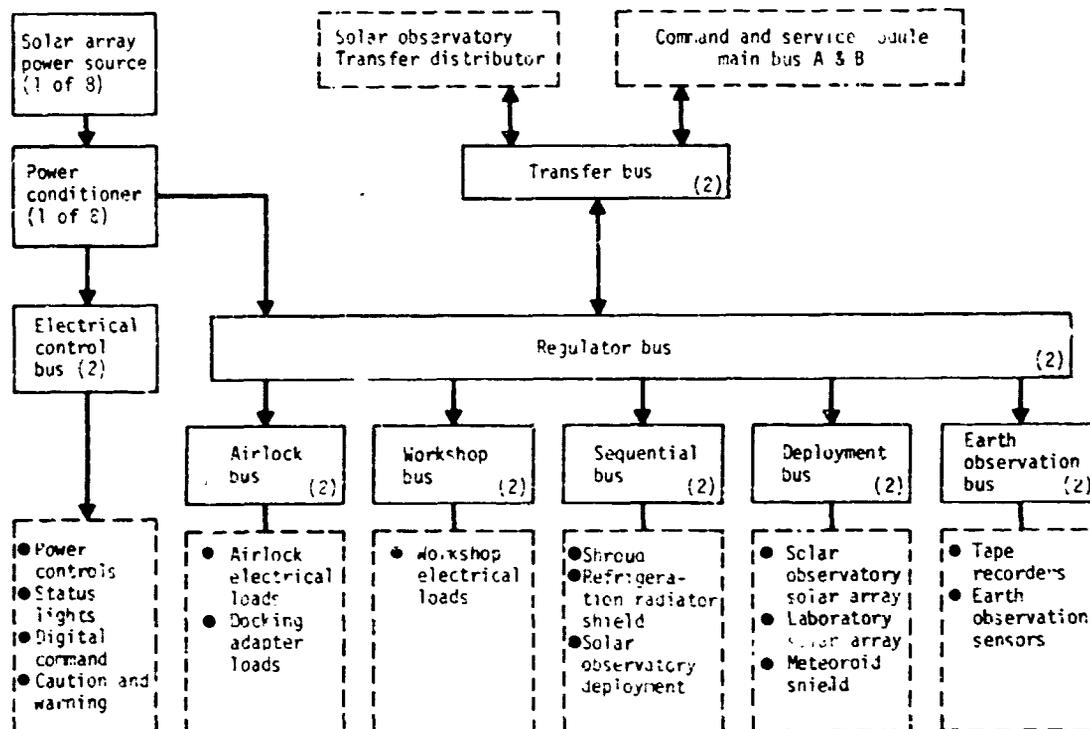


Figure 7-17.- Laboratory power distribution.

loop effects. This is the only ground for the complete Skylab system when the command and service module and docking adapter power umbilical is connected. Sensing and control circuits are used to monitor and protect each system. The redundant command and service module direct current electrical power buses interface with the transfer buses and are powered by the solar observatory and laboratory electrical power systems. Figure 7-18 shows the general location and layout of electrical panels in the airlock-docking adapter area. Figure 7-19 is a view of the panel showing controls and displays used for transfer and distribution of laboratory electrical power.

Distribution of electrical power within the Saturn Workshop was satisfactorily accomplished. Voltage drop levels compared favorably with design data and test results. Power was supplied throughout the laboratory at levels sufficient to maintain the voltage between the required limits of 24 to 30 vdc. The observed range of voltage on workshop buses 1 and 2 was 29.3 vdc maximum to 27.4 vdc minimum from launch through the end of the mission.

**Distribution Control.**- Control of laboratory power distribution is accomplished by ground command or by manual operation by the crew. Status of the control and power configuration of equipment are displayed to the crew by meters and status lights, or by position, while telemetry systems monitor and provide this information to the ground controllers. The positions of the circuit breakers and switches for distribution control were not altered by boost vibration or command and service module docking loads. All power circuitry was successfully operated without incurring any short circuits or discontinuities. All of these switches and circuit breakers contained within the laboratory performed properly, with one exception, during the mission.

- |                                |                                     |
|--------------------------------|-------------------------------------|
| A. Airlock hatch               | E. Laboratory power system controls |
| B. Power distribution controls | F. Laboratory power bus controls    |
| C. Event timer                 | G. Environmental system controls    |
| D. Lighting controls           | H. Airlock handrail lights          |

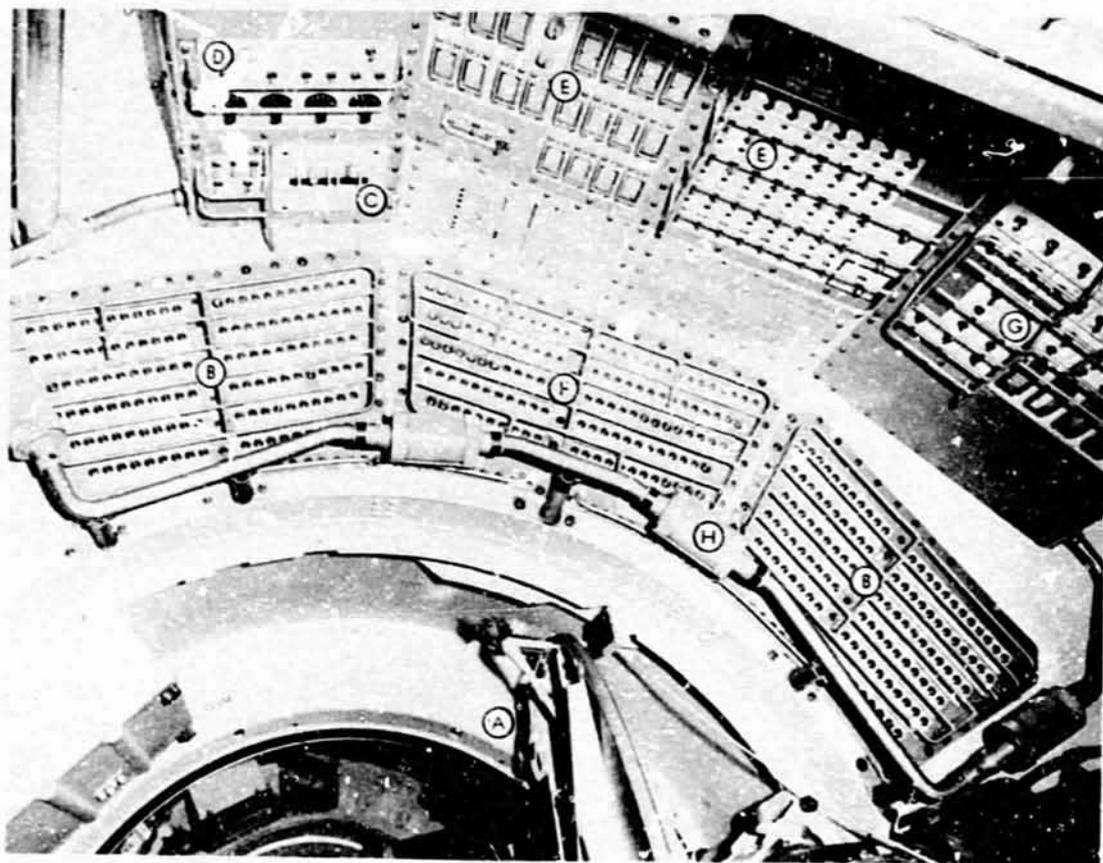


Figure 7-18.- Laboratory electrical control and display panels.

An internal lighting failure in the docking adapter occurred on Day 99, with the loss of the aft lights 2 and 4. Trouble-shooting indicated that a possible cause of failure could have been an intermittent failure of the light switch. After successful reactivation, the switch was taped in the "on" position and the light was controlled locally for the remainder of the mission.

Protection.- The power distribution system uses parallel feeder wire circuit breakers for power transfer. This provides protection of each feeder circuit so that loss of a feeder circuit breaker does not completely eliminate the transfer circuit, but reduces the power transfer capability by a ratio of the number of feeder circuit breakers open to the total number of feeder circuit breakers. There are also two regulator bus tie circuit breakers that tie regulator bus 1 and regulator bus 2 together to provide optimum power capability from the laboratory power conditioners and to provide a means of powering an unpowered regulator bus should this be necessary. There was only one unscheduled opening of a feeder circuit breaker during the first manned period. The workshop bus 1 feeder 2 circuit breaker was inadvertently opened by a crewman but was reclosed without any problem. Transfer bus to command module main bus circuit breakers and regulator bus tie circuit breakers were operated as planned for power transfer to the command and service module.

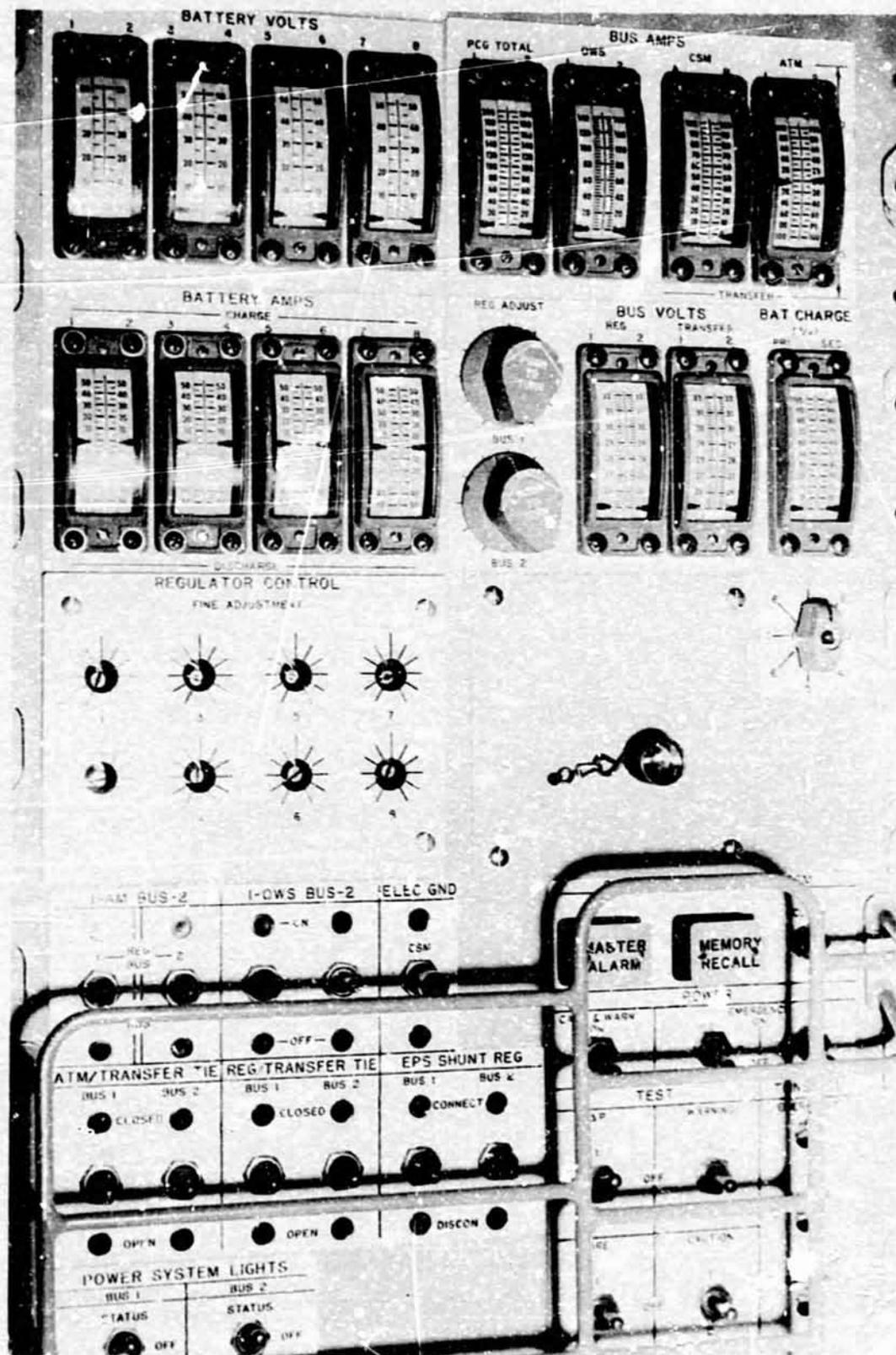


Figure 7-19.- Closeup of laboratory electrical controls and displays.

Other circuit protective devices used are circuit breakers for transfer current monitors and power distribution controls, fuses for voltmeters and regulator bus adjustment circuits, and resistors for telemetry of the workshop bus parameters. All protective devices met the requirements for safe and adequate power distribution. A few times circuit breakers tripped for no apparent reason; however, these were easily reset by the crew with no adverse effects on the mission.

### 7.3 SOLAR OBSERVATORY POWER SYSTEM

The solar observatory electrical power system consists of a 4-wing solar array, 18 power conditioners, distribution buses, and electrical loads. Additional sensors, controls, and displays provide for system management. Under ideal conditions and with continuous sunlight in the solar inertial attitude, the solar arrays are capable of generating more than 11 kilowatts of electrical power. The solar array wings are divided into 18 independent solar panels which provide power to the 18 power conditioners. These power conditioners accept the solar panel power outputs and distribute current to their batteries and voltage regulators. Each is connected to the two main power buses through isolation diodes. The system normally operates in parallel with the laboratory system by means of transfer relays. The power transfer relays may be opened for independent electrical system operation in a contingency mode. The return buses for each system are permanently connected.

The system demonstrated its capability to provide power to overcome the problems caused by the launch anomaly. System performance was stable and predictable, and power output met the design specifications; however, three power conditioners and two solar array panels experienced anomalies.

#### 7.3.1 Solar Array

Each of the four wings is oriented at a 45-degree angle to the longitudinal axis of the workshop and consists of four panels and one half panel. The half panels are electrically paired to form 2 complete panels, which with the other 16 provide the 18 individual solar power sources for the 18 power conditioners of the system. Figure 7-20 shows the physical characteristics of the solar array.

The major factors affecting solar array outputs are essentially the same as those for the laboratory array. Figure 7-21 shows the solar irradiance for the mission period. At the beginning of the mission, the Earth was near its greatest distance from the Sun, so the solar irradiance was approximately 3 percent below the average value. However, at the end of the third manned period, the Earth was near its shortest distance from the Sun, resulting in a 3 percent increase in intensity. The resulting increase in power partially offset the effect of solar cell degradation occurring during the mission. Degradation of power output of the solar cells is caused by penetrating radiation (electron and proton flux), thermal cycling effects, micrometeoroid erosion, and surface contamination.

Thermal Characteristics. Data from 18 temperature transducers located at various places on the solar observatory solar wings are used to estimate the operating temperature of each solar panel. Figure 7-22 shows typical panel temperatures measured for beta angles of 0, 60, and 73.5 degrees. The curve for a 73.5 degree beta angle, or full sunlight, is included to show a typical orbit at a very high beta angle.

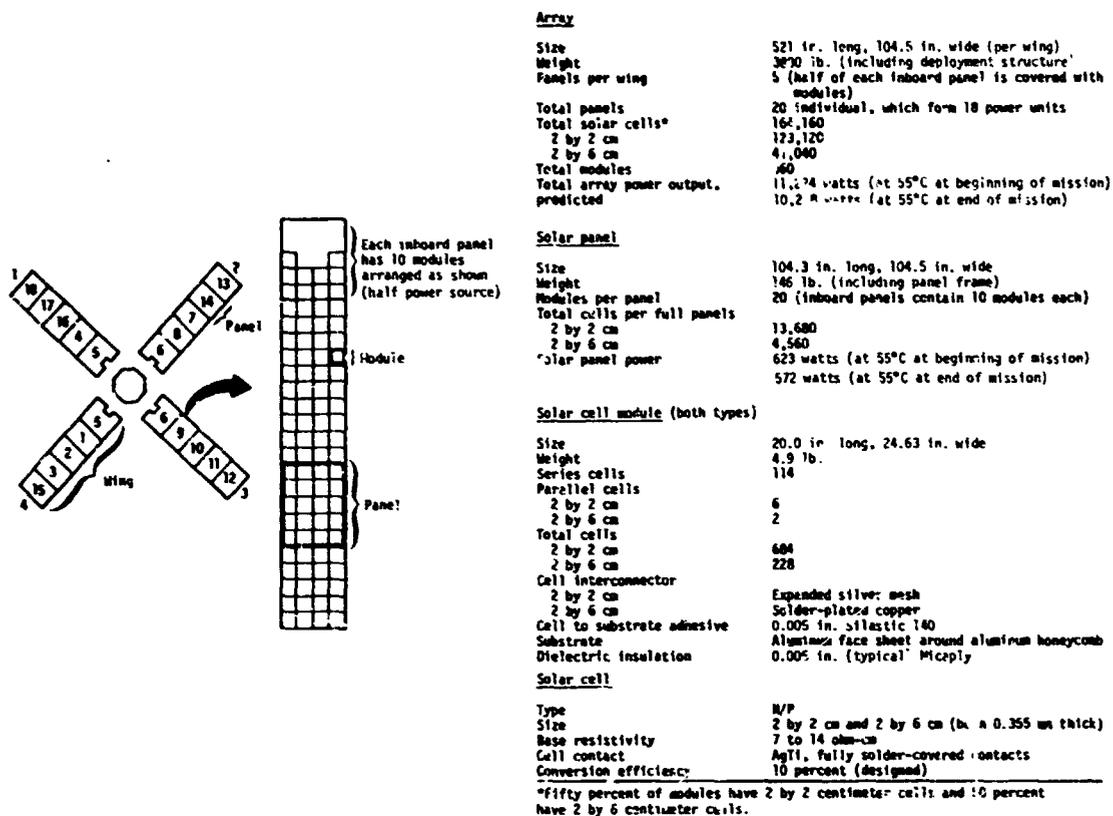


Figure 7-20.- Solar observatory solar array system configuration.

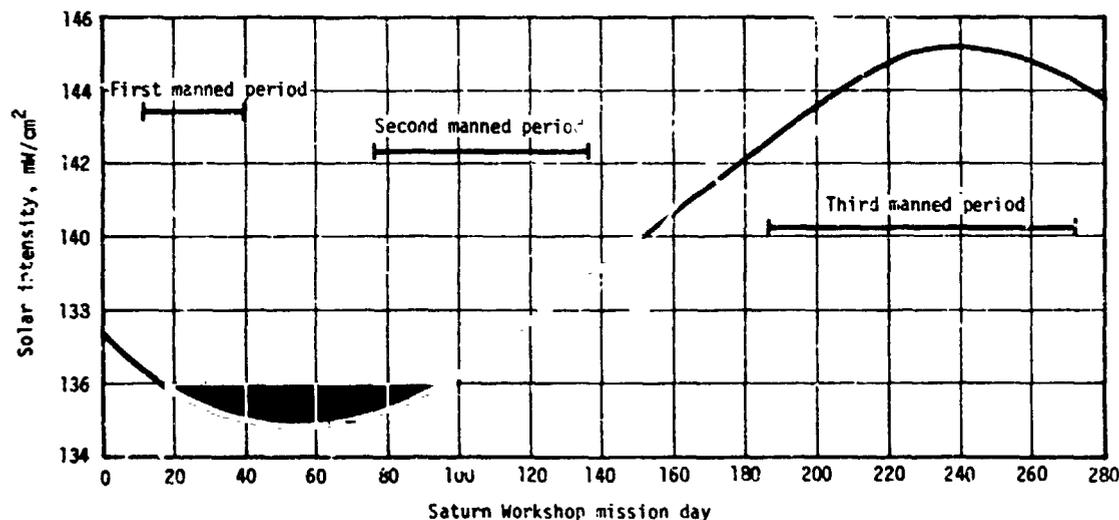


Figure 7-21.- Solar irradiance at Earth distance from the Sun relative to mission time.

Two temperature sensors on panels 7 and 12 were either loose or operating intermittently. Temperature measurement uncertainties continued to be a problem during the third manned period. During the last 14 days of this period, two

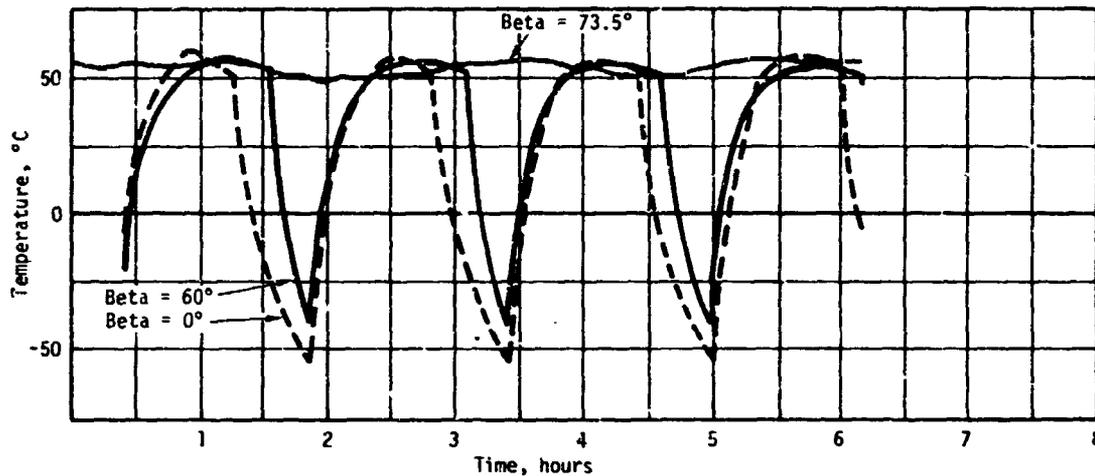


Figure 7-22.- Typical solar observatory solar panel temperatures.

additional panel temperature sensors became faulty, necessitating estimation of true temperatures by use of indirect means. The faulty sensors were on panels 2 and 13.

Panel operating temperatures generally followed predicted patterns, but were significantly cooler because of the absence of reflected heat from the lost solar array wing. As early as Day 3, inconsistent temperature readings were observed. The sensors on panel 7 indicated a gradient of up to 40°C between the front and rear surfaces of the panel in contrast to gradients of 7 to 13°C for the mid-wing panels of wings 1, 3, and 4. Also, temperature time profiles during different orbits and mission times indicated that the panel backside temperatures did not agree with predicted data in most cases.

The front and rear surface temperature measurements on the solar panels do not necessarily reflect the solar cell operating temperatures. Calculations of maximum power degradation are sensitive to temperature. If uncorrected temperatures were used, degradation data dispersions of 20 to 30 percent were common between front and back panel measurements. Therefore, it was necessary to determine the actual panel operating temperatures very accurately to reduce errors and consequent data dispersion.

The Saturn Workshop was operated in a variety of non-solar-inertial attitudes for the first 13 days to reduce solar heating. Knowledge of the exact pointing angles and, consequently, consistent data were unavailable for this period. The pointing system could not compute the Sun pointing angles when the Sun sensor was pointed more than 25 degrees away from the Sun. Approximations of the Sun pointing angles were computed using the solar array power output shadow patterns and temperatures. This unusual use of the electrical system parameters provided data which allowed the attitude of the vehicle to be determined. Data indicated that the attitudes calculated were within a few degrees of actual vehicle attitude.

The solar panels were not designed to withstand temperatures below -70°C. Below this value, the stresses on solar cell interconnects increase rapidly with small changes in temperature. The orbital attitude between Day 1 and Day 12

resulted in many of the solar panels exceeding the  $-65^{\circ}\text{C}$  lower limit of the qualification tests by  $15^{\circ}\text{C}$  or more. The exact number of cycles in which the lower temperature limit was exceeded is not known. This severe exposure significantly reduced the electrical circuit reliability for the solar cells.

Power Output.- The premission power requirement was 10.5 kilowatts at the beginning of the mission with a prediction of an 8.8 percent degradation from all causes by the end of the mission. Solar array performance for the 15 operating panels closely agreed with the preflight predictions, as depicted in figure 7-23.

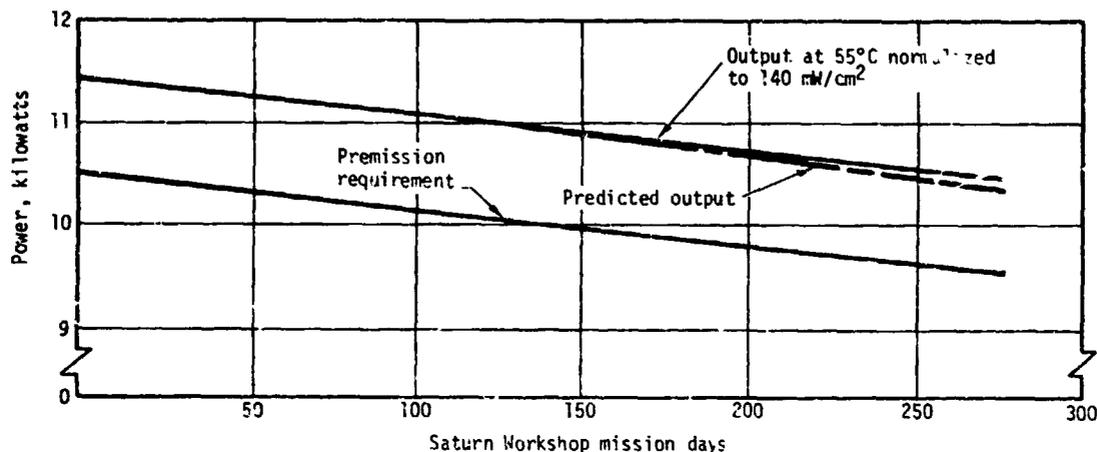


Figure 7-23.- Solar observatory solar array performance.

During the second manned period, Days 76 to 135, the solar intensity increased from  $135.8$  to  $139.4$   $\text{mW}/\text{cm}^2$ , representing a maximum-power capability increase of 2.7 percent. On Day 232, during the third manned period, the Earth to Sun distance was at a minimum and the solar intensity increased to  $144.9$   $\text{mW}/\text{cm}^2$ , representing a power capability increase of 6.7 percent from the start of the second manned period.

Degradation.- Of the 13 panels, 15 operated continuously. Panel 3 ceased operating on Day 17 when its regulator failed, and remained off. Insufficient data points existed to establish a degradation trend for this panel. Panel 5 was not operated after Day 123, when its charger malfunctioned, except for Earth observation maneuvers later in the mission. These panels were not included in the determination of the average degradation rate. Panel 15 was inoperable for an extended period early in the first manned period. However, sufficient data were obtained to establish a degradation trend.

Panel 8 started the mission with a power deficit of between 4 and 6 percent. The first reliable data were obtained during a solar inertial pass on Day 14. Panel 8 showed an additional loss of 6 percent. Solar panel 7, which is adjacent to panel 8, showed similar behavior. Initially, its power capability was 4 to 8 percent greater than predicted by ground test data. On Day 14, panel 7 indicated a 10 percent power loss, or 3.5 percent below predicted. Panel 13 provided 6 percent less power than predicted at launch and continued to degrade at a rate of 2.8 percent per month.

Intermittent power losses on panel 15 were first observed and recorded on Day 206. The step voltage changes which occurred seemed to be due to the cyclic successive opening of as many as two modules on the panel. The first voltage step, of 1.6 volts, occurred at 23°C. The second step, of 5 volts, occurred at 30°C. The cumulative effect of the two steps was the equivalent of a loss of two solar cell modules. This resulted in a power loss measured in the constant current range of operation (13.4 amperes) of approximately 13 percent for the panel (0.8 percent for the array). The orbit-to-orbit regularity of the change suggests a thermal-related making and breaking of a connection which intermittently open-circuited the module. The problem occurred late enough in the orbit each time to allow normal battery charging and not affect the mission during solar inertial operations.

The panel 17 regulator output current was highly erratic. The fault, which reduced the regulator output to 20 percent capability, was isolated to the solar panel. The problem apparently was the result of a solar panel electrical short to the structure. This problem disappeared on Day 151. The degradation shown by the panels can be explained by expected failure mechanisms and by the extremely low temperatures reached by the solar panels between Day 1 and Day 12, which often exceeded qualification test limits and could have significantly affected the degradation rate for each panel, depending upon its location and thermal characteristics.

Some discoloration of the white thermal paint on the underside of the wings was observed by the first crew. They reported that the wing undersides were darkest near the solar observatory, becoming lighter toward the wing tips. Darkening of the paint caused a change in the thermal characteristics of the panels. However, the discoloration had no apparent effects. During the first crew's docking, flyaround, and undocking maneuvers and the second crew's docking maneuver, the array wings were exposed to thruster exhaust. While the individual exposures were short, the total exposure during these maneuvers was sufficient to cause concern about accumulated contamination and flexing of the solar array wings due to mass impingement. Films taken during rendezvous, docking, and flyaround maneuvers indicate that the wings flexed as much as 1 foot at the tips in either direction as a result of impingement of exhaust from the command module thrusters. The mechanical stresses induced by this flexing on the solar panels could not be determined with the instrumentation available.

The power capability status of the solar observatory array as of Day 269 was assessed and compared with preflight performance measurements. The results are given in Table 7-VI. Based on the end-of-mission status, the average degradation rate over the entire mission was 0.9 percent per month.

Table 7-VI. - Solar Observatory Solar Array System Status  
At End of Mission

Item	Value	
Day	269	Note: Three panels were not considered in the degradation calculation because of temperature transducer anomalies. Also, the solar array panels for power conditioners 3 and 5 were not on line and thus were not considered.
Beta angle, degrees	+15	
Revolution	3874	
Panel current, amperes (fixed)	13.4 ± 0.3	
Orbit position, minutes after sunrise	19	
Direct solar intensity, mW/cm <sup>2</sup>	144.1	
Average panel temperature, °C	41	
Power output, 16 panels, watts	9596	
Average degradation for 13 panels, percent	8.6	

### 7.3.2 Power Conditioners

The power conditioners are similar to those in the laboratory system and are controlled by switch operation or digital address commands. The maximum power output of each module is approximately 415 watts. The redundancy afforded by the 18 power conditioners was capable of compensating for all electronic problems; however, multiple battery degradation caused some concern. The battery degradation was a direct result of excessive discharge levels, improper charge regimes, and high battery temperatures that occurred when forced to operate at non-solar-inertial attitudes. Accelerated ground test data indicated that the batteries would recover by the beginning of the second manned period.

Twice during the mission, the power capability of the power system was exceeded, causing the depletion of battery power in eight conditioners. This resulted in automatic battery disconnect. The first time this happened, an unexpected automatic regulator trip occurred upon entry into sunlight, which caused the input power contactor to disconnect the solar array from conditioner 15. The contactor failed in this position, probably because of debris or mechanical failure. Confidence in the contactor was not affected, however, as some test units had been operated for more than 250,000 cycles.

Chargers.- The charger is a stepdown, single-ended regulator which conditions the inputs from the solar array source to the level required for charging the battery while achieving maximum use of array power. The solar arrays feed power to the charger and bus regulator in parallel. The regulator load demands are supplied first, and the remaining power charges the batteries. The charger senses solar array voltage and current, battery temperature, charge current, electrode voltage, and output voltage for charge control. All chargers functioned normally until Day 123, when the battery charger of power conditioner 5 failed while charging, causing the overvoltage sensor to disconnect the battery automatically from the system. The failure allowed the solar array power to feed directly to the battery without conditioning. Power conditioner 5 was not used again until near the end of the mission. A workaround was developed to combine the power conditioner 5 regulator and the power conditioner 3 charger and battery by use of jumpers. This modification was carried up by the third crew but was not implemented.

Near the end of the third manned period, in a critical power situation during Earth observation operations, power conditioner 5 was turned on to provide added power, since the charger failure mode basically allowed the charge voltage to exceed the maximum programmed voltage by 1 volt. Automatic disconnect circuits terminated the charge at this point. The power conditioner functioned under these conditions and maintained the battery operating parameters within their safe limits.

Batteries.- Each battery consists of 24 nickel-cadmium, 4-electrode, hermetically sealed cells connected in series. Two electrodes in each cell provide sensing for charge control; the third electrode recombines hydrogen and oxygen to prevent excessive internal cell pressure and discharges the fourth electrode.

Each has a rating of 20 amp-hr when fully charged. The operating voltage is 24 to 32.5 vdc when discharged in the load range of 0 to 10 amperes. The life requirement is 4000 discharge-charge cycles at an average maximum depth of

discharge of 30 percent. Automatic electrical heaters and passive cooling are used to control battery temperatures. Flag indicators on the control and display console alert the crew to high or low voltage, high or low temperature, or failure to recharge the battery.

The batteries were sized to provide an average of 220 watts each with peak anticipated loads of 540 watts. This load is equivalent to a 20 percent depth of discharge. Maximum allowable discharge at any time was limited to 50 percent. Anticipated battery temperatures for the mission were between 0 and 20°C.

To achieve optimum battery performance, a charge was used which ensured the maximum available capacity and cyclic efficiency with minimum charging time and cyclic heat generation. Critical charging parameters were the initial high-rate charge, the voltage level at which the charger switches to low rate, and the third-electrode-generated charge termination. Charging was also terminated if the temperature limit was exceeded. Figure 7-24 shows the desired battery charging method.

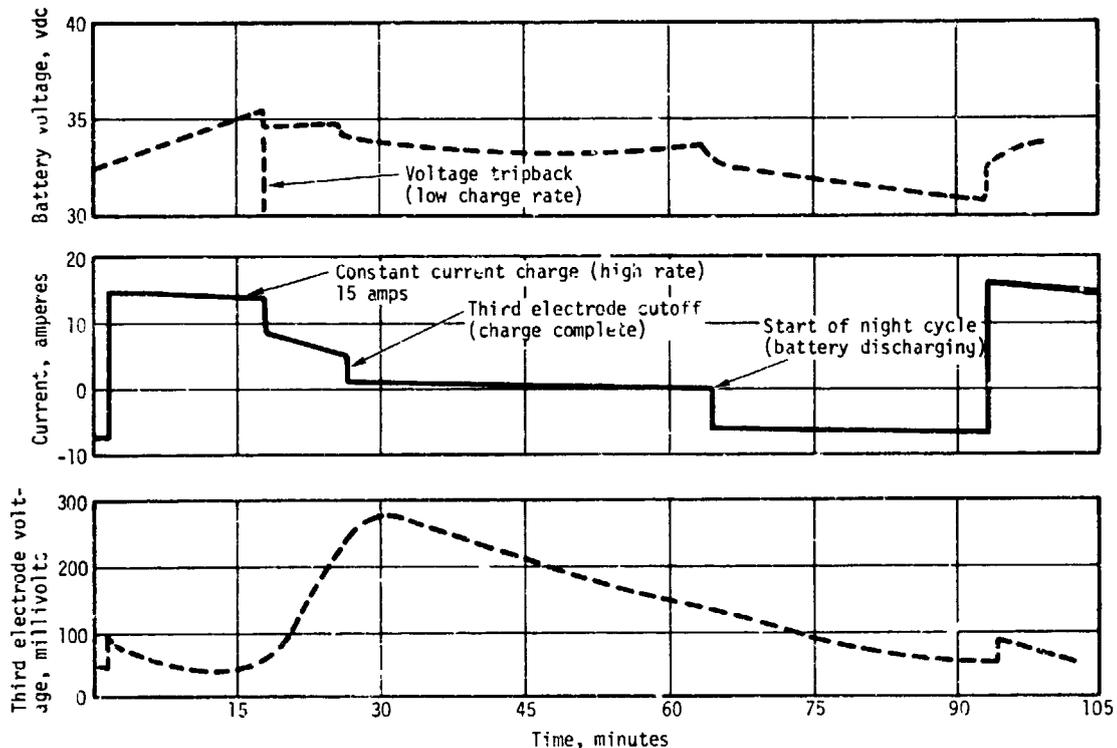


Figure 7-24.- Battery charge method.

After the power systems were paralleled on Day 1 and all laboratory output power was disconnected from the buses, the solar observatory power system provided all the power until Day 25. During this time, the batteries were managed with energy balance as the goal; however, the batteries were allowed to go below energy balance during many orbits. The attitude was constrained during the first unmanned period so that the batteries were recharged before resuming the preferred thermal attitude.

Deepest discharges were observed on Day 17 following the first Earth observation pass with battery 11 discharging 54 percent. Battery 11 also experienced

the maximum battery discharge rate that occurred during the mission (14.2 amperes). The maximum allowable rate was 20 amperes. In this period 4 regulators had been shut off, and the remaining 14 batteries provided all of the required power.

Specific power conditioner outputs were turned off during charging to allow the batteries to recharge at a higher rate. Power conditioners 5 and 6 required extensive management because of canister shadowing of their array panels when the vehicle was out of the solar inertial attitude.

Battery cycling performance from the time of the workshop solar array wing deployment until the undocking of the first crew was satisfactory. During the first unmanned period 166 cycles were accumulated, and 420 cycles were accumulated during the first manned period. The discharge and charge modes of battery operation were as predicted for the lower discharges after Day 25. The depth of discharge experienced during the first manned period was 25 to 32 percent before the wing deployment. Afterward, the discharge was between 0 and 23 percent. Continuous sunlight was available to power the vehicle for the initial 4 days of the second unmanned period because of the high beta angles. The batteries were trickle charged for this time. Charge and discharge cycles started again on Day 44, and the total accumulated cycles reached 1137 by the end of the period. The batteries had 2054 flight cycles at the time the second crew departed on Day 135. The discharge depths during the second manned period were 14 to 24 percent, except during Earth observation passes when they were as high as 50 percent. The cycles had reached 2853 by the end of the third unmanned period and 4108 when the third crew left.

Capacity tests during the second manned period were run on five different batteries to determine an acceptable limit to which the batteries could be discharged. Capacity was determined by integrating the battery current over the total discharge period. The tests were run again on batteries 10 and 13 on Day 195. However, these tests were run at a lower rate than the other tests, which invalidated the results. These tests were successfully rerun on Day 229. During the final week of the mission, ground control performed capacity-discharge tests on the 16 operating batteries. Previous tests had been run to the talk-back level (27.5 volts), and a "worst-case" value of 1.1 amp-hr was added to the capacity obtained to determine probable usable capacity. This was done to prevent possible problems in reconnecting the power conditioners if they automatically disconnect. These final tests were run to automatically disconnect. Except for battery 7, the 1.1 amp-hr factor used on previous tests was more than adequate. These results are shown in tables 7-VII and 7-VIII.

This loss of capacity characteristic was first observed on Day 17 when, during an Earth observation pass, several batteries were automatically disconnected because of low voltage. The capacity, which was expected to be at least 15 amp-hr, was approximately 8 amp-hr. Subsequent average capacity checks on Day 122 (11 amp-hr) and Day 229 (10 amp-hr) indicated that the available capacity increased after Day 17 and remained near that predicted during the remainder of the mission. The capacity losses are shown in figure 7-25. Although the capacity loss did not seriously affect the mission, it was unexpected and unexplained.

The evaluation of the capacity loss requires the definition of two factors, memory and fading. Memory is a capacity loss which has been demonstrated to be recoverable. The memory variables are temperature and discharge. Fading is

Table 7-VII.- Battery Capacity Tests

Battery	Mission day	Capacity (estimated to autodisconnect), amp-hr	Note: A crewman monitored each test and terminated battery discharge when he observed the battery voltage flag which indicated battery voltage of 27.5 volts. 1.1 amp-hr was added to the measured capacity to obtain total capacity which would result if the battery was allowed to discharge to automatic disconnect at 26.4 volts.
7	93	12.1	
10	102	12.4	
18	102	13.1	
5	104	12.1	
8	104	12.5	
10	105	12.2	
18	105	12.9	
10	118	11.1	
10	119	12.4	
10	122	11.6	
5	122	11.1	
10	195	3.0 (Tests run at low discharge rate)	
18	195	13.0	
10	229	9.2	
18	229	10.66	

Table 7-VIII.- End-of-Mission Battery Tests

Battery	Day	Capacity, amp-hr		Capacity differences between talkback and automatic disconnect, amp-hr
		At voltage talkback level (27.5 volts)	At automatic disconnect	
1	267	7.8	9.7	1.9
2	255	No data	10.9	-
4	268	10.0	11.4	1.4
6	270	7.7	9.5	1.8
7	269	6.2	7.2	1.0
8	267	7.5	8.9	1.4
9	267	8.8	11.5	1.7
10	265	7.2	11.9	4.7
11	268	8.3	10.0	1.7
12	268	9.0	11.1	2.1
13	265	No data	9.8	-
14	266	No data	11.2	-
15	270	10.1	11.6	1.5
16	269	6.9	8.7	1.8
17	269	No data	8.9	-
18	265	7.8	11.5	3.7
Average	-	8.1	10.2	2.1

defined as a permanent loss in capacity and is essentially a form of accelerated aging. Fading remains a subject of investigation to determine in quantitative terms what the relationships to mission conditions are. This information will be of considerable importance in future long term space missions.

The other battery parameters, such as recharge fraction, efficiency, and third-electrode controls, remained relatively constant throughout the mission. Life test data confirmed these observations. The recharge fraction remained approximately 110 percent at a 20 percent depth of discharge at 10°C with a corresponding efficiency of 80 percent. A change in the characteristics of battery 9 occurred during the third manned period which resulted in the battery not being recharged following each dark period. This occurred only at beta angles greater than 60 degrees, which corresponded to a dark period of less than 20 minutes. These short discharge periods did not discharge the battery enough to cause the third-electrode voltage to drop below 200 millivolts. This inhibited the charger through the next daylight cycle. During the subsequent dark period

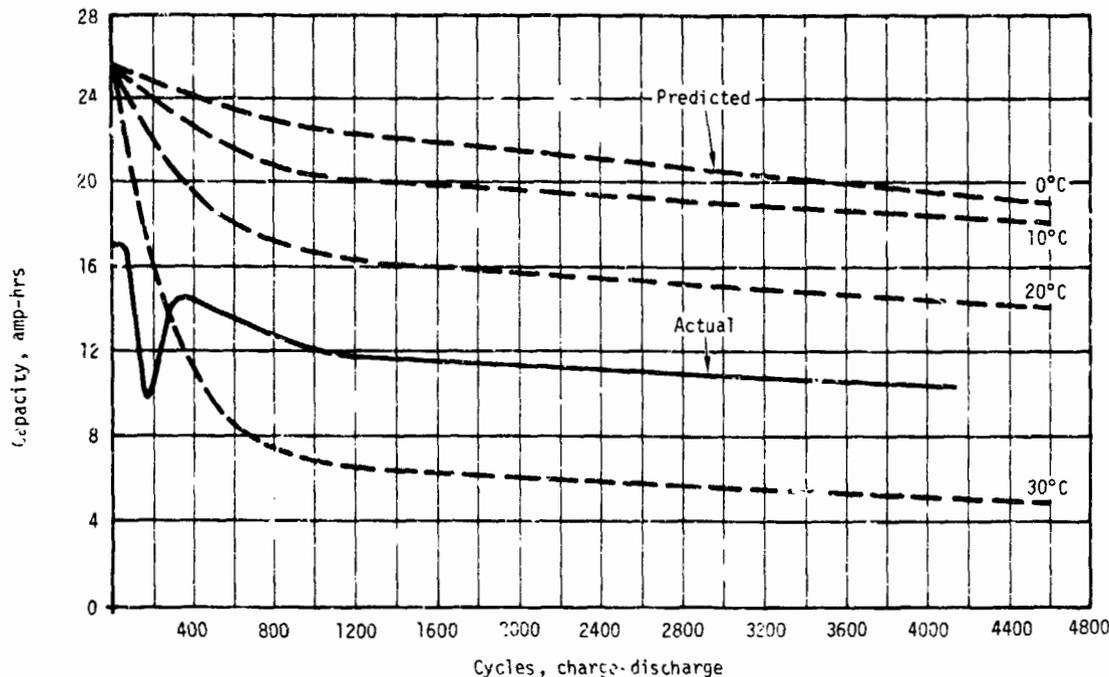


Figure 7-25.- Solar observatory batteries' capacity degradation.

the battery was discharged further, removing the 200 millivolts signal from the third electrode, allowing normal charger operation. In effect, this condition resulted in two battery discharges for one charge. Although the cycles were not normal, the battery was not being abused and could function indefinitely in this mode. Normal cyclic operation resumed when the discharge time again became greater than 20 minutes.

Regulators.- A wide range of input voltages (25.5 to 30 vdc) must be regulated for use. Each regulator is a single-ended switching circuit which increases or decreases the input voltage by employing dump-or-store regulation to maintain the required output. Input voltages are supplied by either the solar array or the batteries. Output voltages are maintained between 30.4 vdc at no load and 27.1 vdc at full load, which is current-limited to 20 amperes maximum even under output short circuit conditions. Sensing is provided to activate a crew alert indicator if regulator output increases to  $31.8 \pm 0.2$  vdc or drops below  $20 \pm 1$  vdc.

Circuit protection logic automatically removes the regulator from the line if the output voltage exceeds  $31.8 \pm 0.2$  vdc. Automatic recovery is not provided. The regulator may be brought back on the line when the output voltage returns to acceptable limits by first turning it off and then turning it on. This control can be accomplished by switches on the control and display console, by the digital address system keyboard, and by ground command.

The only regulator failure noted during the mission was in power conditioner 3. A failed component in the control circuit on Day 17 caused the loss of output. Onboard status lights indicated the "regulator on" command was getting to the unit. All other functions of the power conditioner were normal. Also on

Day 17 and subsequently during the mission, fluctuations of  $\pm 1$  ampere in the regulator 4 current were noted. The problem was believed to be caused by an open capacitor used in an internal RF filter. The fluctuations were not evident on the load bus and had no effect on total performance. Average regulator efficiency was measured using the main bus voltage. Using a 20 percent depth of discharge and attributing battery diode loss against the system as a whole, the regulator efficiency was calculated to be 92.4 percent during sunlight periods and 89.3 percent during the dark portions of the orbits.

During the mission it was noted that the depth of discharge of battery 11 was greater than that of the other batteries. This was explained by the fact that the regulator characteristics of power conditioner 11 when it was ground tested showed that it tended to provide slightly higher output power than the others. The power sharing circuit was tested at the end of the mission by switching both primary and secondary remote sensing circuits off and observing the anticipated 0.3 volt drop in bus voltage predicted from premission ground testing.

### 7.3.3 Power Distribution

**Distribution Networks.**— The solar observatory power distribution system consists of 2 main power buses fed directly from the 18 power conditioners. Downstream are several redundant subsidiary buses which supply their respective subsystem electrical equipment. Power is distributed through the power transfer distributor, main power distributor, auxiliary power distributor, six control distributors, and three measuring distributors. Figure 7-26 is a diagram of the solar observatory electrical power distribution system. Figure 7-27 shows the electrical system controls and monitors located on the solar observatory control and display panel in the docking adapter.

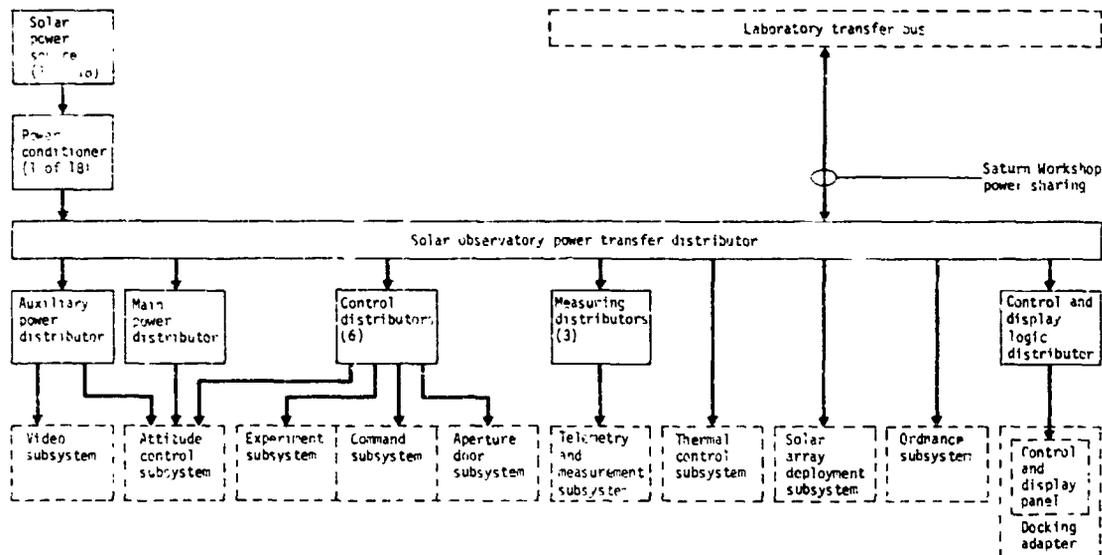


Figure 7-26.— Solar observatory power distribution.

The solar observatory power distribution networks met all mission requirements with one exception. On Day 183 a 500-ampere current spike was observed on television bus 2 for 3 seconds. The bus voltage went to zero. After considerable

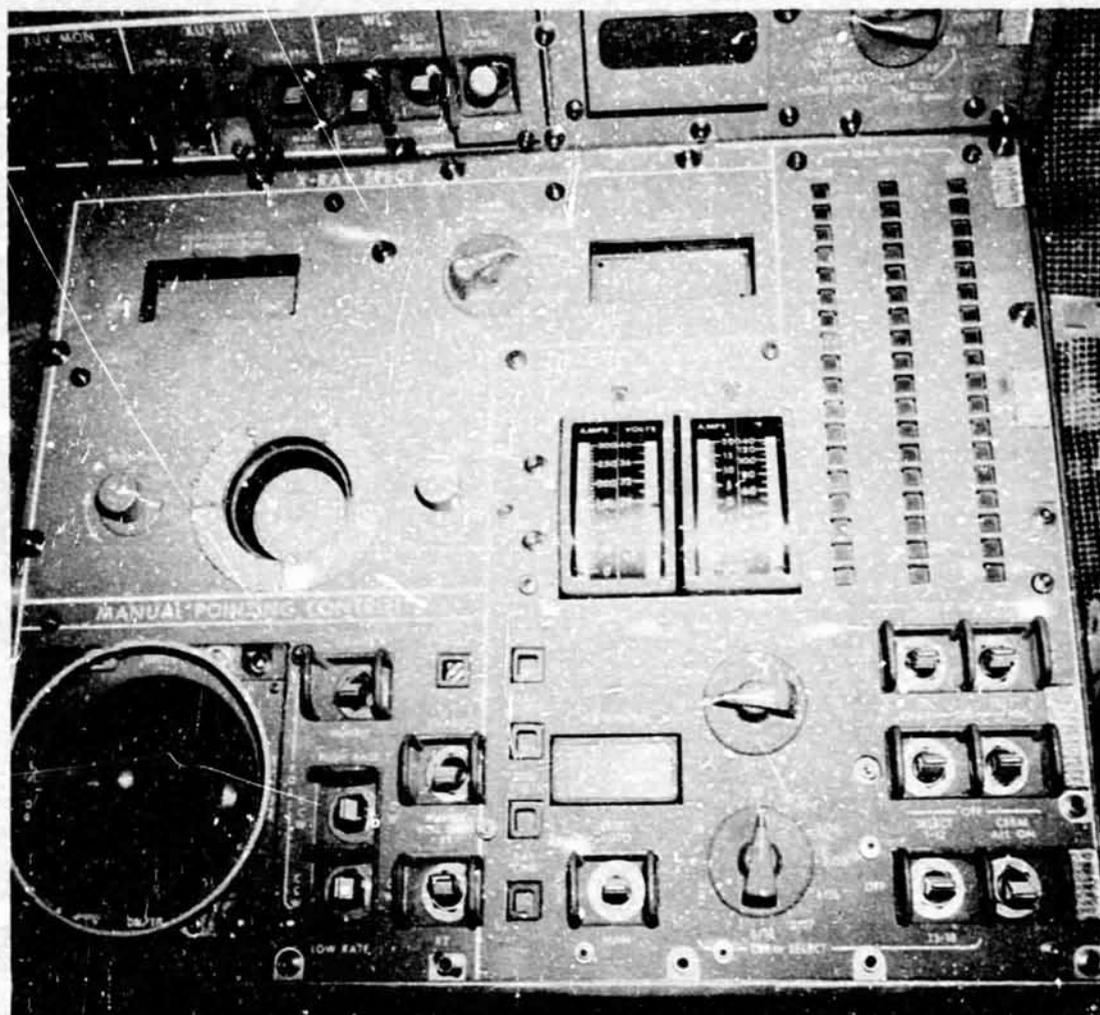


Figure 7-27.- Closeup of solar observatory electrical controls and displays.

ground analysis and simulator testing, it was determined that a hard short from the bus to the ground had occurred in the power transfer distributor. Power feeder lines, although protected by fuses, could not sustain the short. The location of the short and the extent of the damage could not be assessed. The television bus 1 was sufficient to provide power for the remainder of the mission. A workaround cable was provided for the third crew as a backup to television bus 1, but was not used.

After the third crew's departure and before the final vehicle powerdown, a brief period of time was allotted for conducting electrical power distribution closeout tests. The electrical system bus redundancy design was tested to check its reliability. The procedure consisted of alternately turning off each subsystem's redundant bus. Telemetry responses monitored during this time confirmed that all subsystem loads remained active while the buses were cycled except for the television system. The test verified that the secondary television bus had been lost because of the short on the bus during Day 83. The primary measuring bus operated without degradation throughout the entire mission. The secondary measuring supply was activated to determine its capability. Activation was successful and there was no noticeable degradation.

Distribution Control.- Control of the solar observatory power distribution is accomplished by ground command or manual operation by the crew. Status of the control and of the equipment power configuration is displayed to the crew by onboard meters and status lights and is telemetered to the ground. This dual capability gives the crew control while relieving them of routine operations, which are performed by ground control, and also provides system and experiment operation capabilities during the unmanned periods of the mission.

Controls, monitors, onboard displays, and telemetry of bus voltages and currents provided satisfactory operation of the power distribution system, with the following exceptions. Overall circuit control was satisfactory except that the X-ray spectrograph's main power could not be turned off by normal procedure and the doors of the X-ray spectrograph, ultraviolet scanning polychromator spectroheliometer, and X-ray telescope failed to operate at various periods during the mission. This was largely due to faulty relays in the switch selectors or mechanical friction on the doors. On Day 144, after the issuance of several "main power off" commands to the ultraviolet scanning instrument, the experiment's power remained on. These commands were sent from the ground during the third unmanned period. During the third manned period panel activation on Day 187, the ultraviolet scanning instrument was configured to operate on secondary power, and no further onboard troubleshooting was attempted.

After the third crew's departure the primary hydrogen alpha 2 door motor logic circuitry was tested to verify the operational status of the primary motor circuitry and motor. The procedure called for inhibiting both primary and secondary motor power and reenabling the primary circuitry. Reenabling of the primary circuitry failed to produce a door motion indicator signal, indicating the loss of the primary drive circuitry. A possible cause could have been a short in the drive motor or associated circuitry resulting in a blown fuse. Also, the X-ray spectrograph and ultraviolet scanning instrument command capabilities were investigated further. The test procedures served primarily as additional troubleshooting to determine why the ground could not command each experiment instrument's main power off. Ground commands were issued to turn off each instrument's main power, and real-time data were analyzed. Analysis of the X-ray spectrograph problem indicates the most probable cause was a power relay which failed in the set position, since both ground and earlier panel commands to deactivate were unsuccessful. Because of limited feasible troubleshooting approaches, only suppositions about the ultraviolet scanning instrument problem can be drawn. Probable causes were a relay failure or an open circuit in the command line to either of the two relays involved.

Protection.- Circuit breakers and fuses provide circuit protection for the power system. All wire is protected to limit wire temperature to less than 200°C. Diodes provide circuit isolation. The sizing of these components allowed enough power to be applied to all end items operated during the mission while providing the necessary vehicle wiring protection. Experiment door motor protection circuits use timers to automatically inhibit power to the windings after approximately 60 seconds if a door fails to operate because it is stuck or jammed.

Circuit protective devices and designs provided safe and adequate power distribution and control through the mission. However, as mentioned previously, the fuses apparently could not provide the reaction time required during the

hard television bus short, and there was damage to that feeder. This was suspected since several discrepancies affecting panel control and monitoring of the power system occurred. These possibly could have been caused by debris from the short.

#### 7.4 PARALLEL OPERATIONS

The major controls involved in the parallel operation of the two power systems are those required for normal paralleling sequence, for disconnecting the power lines in the event of an emergency, and for power sharing. The connections between the solar observatory buses and the laboratory buses are accomplished by circuit breakers and relays. The relays are controlled by the transfer switches. These switches are normally controlled from the ground. Manual switches are provided so that the crew may disconnect all loads from the power system involved in the event of a fire or a low bus voltage condition. The laboratory electrical system has two switches that remove all power except for essential loads on control buses. The solar observatory electrical system has an emergency switch which deenergizes all solar observatory loads and also opens the transfer bus ties. Onboard monitoring of the current flowing between the solar observatory and transfer buses is provided. Other parameters required to evaluate the parallel operation of the power systems, laboratory regulator bus voltages and currents, and transfer bus voltages are also displayed.

The power sharing between the solar observatory and laboratory electrical power systems is controlled by adjusting the voltage of the laboratory power system. The laboratory regulator bus voltages vary according to load demands on the system. Predicted values of paralleled power capabilities are derived by assuming an open circuit voltage, which is constant. The open circuit voltage is defined as the regulators' outputs under a no-load condition. The characteristic voltage decrease of the regulator outputs in the normal operating range is 0.01 volt for each ampere of load current. The equivalent open circuit voltage is derived by adding the actual regulator bus voltage and 0.01 times the bus load current. For example, for a regulator bus voltage of 28.67 vdc and a bus current of 43 amperes, the equivalent open circuit voltage is 28.67 plus 0.43, or 29.1 volts. The required open circuit voltage to provide the proper load sharing for a given condition is computed, and the amount of adjustment of the regulator output control to achieve this value is specified. This adjustment is made by the crew by turning the onboard potentiometers to the prescribed setting. The adjustment cannot be controlled by the ground controllers.

The intent of the original open circuit voltage setting was to limit the maximum depth of discharge to 30 percent on the solar observatory batteries and 15 percent on the laboratory batteries. The lesser depth of discharge allowed for the laboratory batteries was specified because of the loss of the solar array wing 2 power. To ensure that these depth-of-discharge constraints would not be violated, an open circuit voltage setting of 29 vdc was selected. The total capability of the electrical power systems at this setting was adequate to supply the total load requirements of the first manned period with a 500-watt positive power margin. This setting was revised at various intervals throughout the mission to satisfy load requirements under changing conditions.

Because some of the command and service module's equipment requires continuous operation, its power system was paralleled with the Saturn Workshop systems before its fuel cell power system was shut down. There was no evidence of

degradation of any electrical power system parameters resulting from these parallel operations. Power transfer to the command and service module buses was as high as 2700 watts during checkout and reentry simulation. Power transferred from the laboratory power system after it was activated was as high as 450 watts. These values do not include the short that occurred on the solar observatory television bus 2 on Day 83. Enough power was provided to this short by the combined power system to clear the short in approximately 3 seconds.

## 7.5 ANOMALIES

The anomalies described in this section were the results of component failures in equipment in inaccessible locations, making examinations of failed items unfeasible. Tests, simulations, and data analysis permitted in most cases a localization of the failure. The use of power margin management and an alternate power distribution bus allowed satisfactory performance of the electrical power systems throughout the mission.

### 7.5.1 Solar Array Power

Solar observatory solar array power output from several panels showed step changes. Simulation tests performed on the ground equipment and evaluation of flight data supported the theory of open or short circuits in one or more of the modules in some of the panels. The extreme temperatures early in the mission and disturbances from the command and service module thrusters during flyarounds probably account for most of the failures.

### 7.5.2 Power Conditioners

There were three problems associated with the solar observatory power conditioners. Figure 7-28 is a simplified schematic of the locations of the affected power conditioners' suspected fault areas.

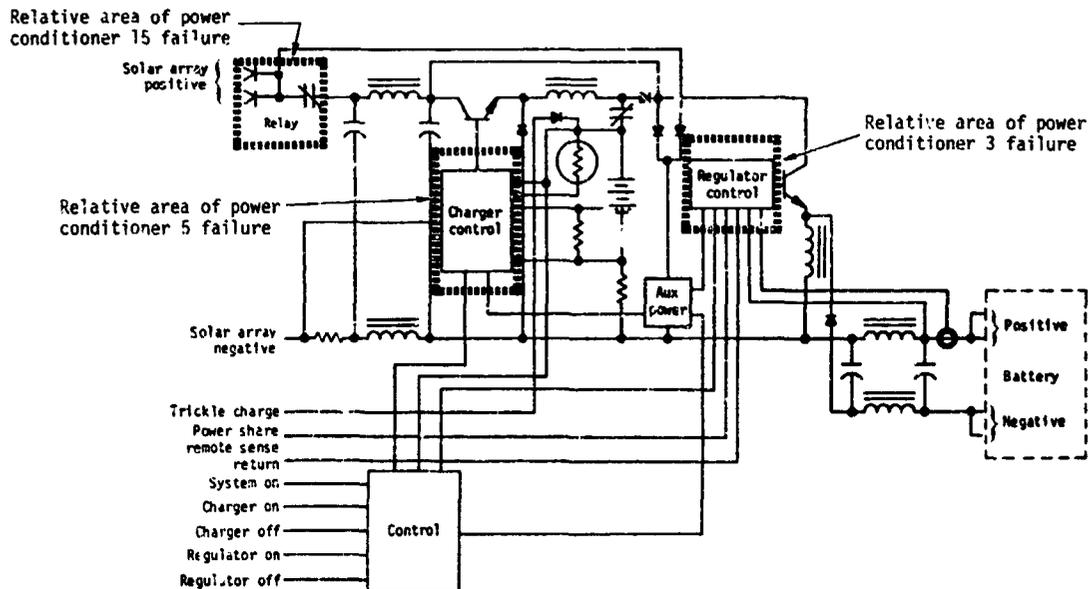


Figure 7-28.- Solar observatory power conditioner areas of suspected faults.

Regulator 3 ceased to deliver power on Day 17. All other functions of power conditioner 3 were normal. Talkback from the regulator command was received, and

there was no other indication of a short circuit or high current that might result from a power component failure. It was concluded that the failure resulted from a connection or component failure in the regulator control circuit.

Charger 5 failed on Day 123. Evaluation of the data and crew troubleshooting indicated that the power conditioner 5 input bus was shorted to the battery relay. The most likely cause was a short in one of the charger transistors; however, it could have been a battery isolation diode failure. This short caused the solar panel output to be tied directly to the battery, so that the battery would be charged until the high voltage cutoff sensor automatically disconnected the battery. Since the charger could not be repaired, the charger and regulator were turned off for the remainder of the mission, except for three Earth observation passes when additional power was required and charging termination was commanded from the ground.

There was no solar panel input power to power conditioner 15 on Day 12. The solar array contactor had tripped open when the conditioner had automatically disconnected from the power bus by the low voltage sensing circuitry. Repeated efforts to close the contactor were without success. Past experiences and ground tests indicated that a crewman should mechanically shock the case at a predetermined point during the next scheduled extravehicular activity. This action restored normal operation, which lasted for the remainder of the mission.

#### 7.5.3 Television Power Bus

There was a command and service module master caution and warning alarm on Day 83. This was followed 1 second later by a 500-ampere current spike on television bus 2. One second after this, the fine Sun sensor wedge-position count and the television bus 2 voltage went to zero. Investigation of the television bus short circuit fault included determination of the possibility of other wiring or components being damaged, and the correlation of other vehicle systems and experiment systems data with this anomaly. Analysis of all power feeder lines from the power transfer distributor was performed. Tests were conducted on the ground on 10-ampere and 15-ampere fuses, and on the current handling capacity of size 15 and 20 wire. Testing of the television bus 2 circuitry was performed in the prototype power transfer distributor. The test wires burned open in 1.8 to 2 seconds at 355 amperes, scattering copper debris inside the distributor. Adjacent wires were not burned open, and the bus arrangement withstood the current surges.

It was concluded that a hard short from television bus 2 to ground had occurred in the power transfer distributor, resulting in the loss of the voltage telemetry signal for that bus and loss of the bus. The location of the short and the extent of the damage could not be assessed.

## SECTION 8 THERMAL CONTROL

The Saturn Workshop is heated by solar and Earth radiation. Additional heat comes from equipment operation and crew metabolism. Temperatures could range widely, but are controlled within the ranges required for materials, equipment characteristics, and crew comfort by a combination of active and passive systems. Passive systems control the gross rate at which heat enters and leaves the laboratory, and active systems provide additional control and proper heat distribution. Auxiliary systems provide suit cooling, equipment cooling, and refrigeration. These systems are described and their performances evaluated. The laboratory and solar observatory systems are largely independent and are treated separately, as are some auxiliary systems. System anomalies are discussed in some detail, and additional information is contained in references 8, 9, and 10.

### 8.1 LABORATORY THERMAL CONTROL

#### 8.1.1 Passive Thermal Control

Insulation, surface coatings, and other passive elements perform a major role in keeping temperatures within the laboratory at acceptable values. The basic insulating materials are fiberglass reinforced polyurethane foam, fiberglass, and multilayer insulation (fig. 8-1). Fiberglass curtains on the airlock both insulate it and protect against penetration by micrometeoroids. The meteoroid curtain has an off-white fiberglass cloth exterior facing and is gold coated on the other facing.

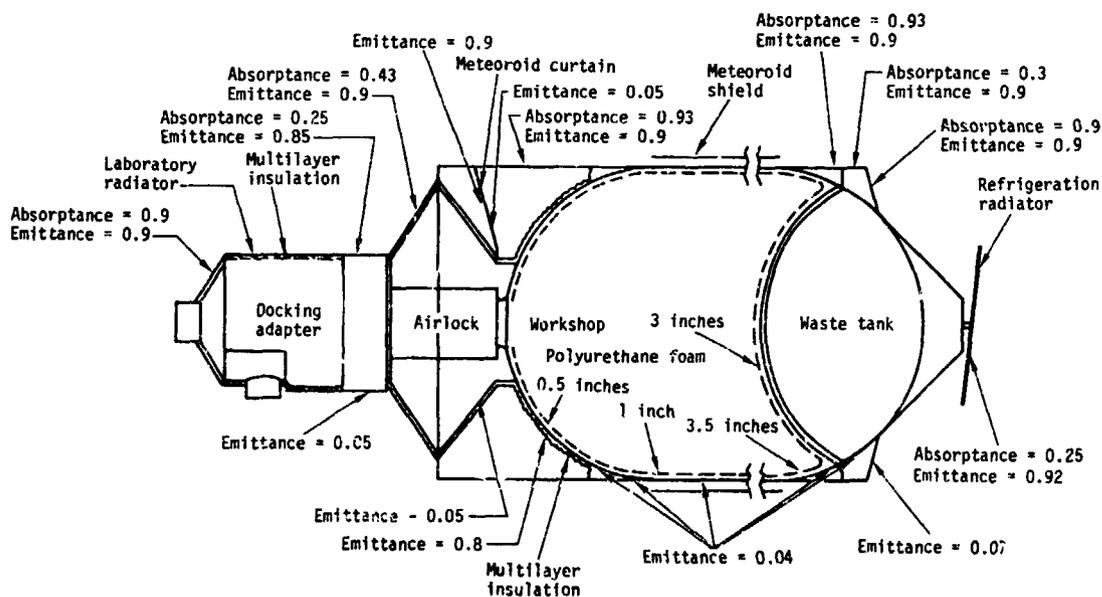


Figure 8-1.- Surface coatings and insulation.

The thermal curtain is impregnated with Viton rubber on one face and has a gold coating on the other face. Multilayer insulation on the workshop forward dome (fig. 8-2) consists of 48 layers of aluminized Mylar and Dacron net, held together by nylon buttons. Its insulating properties derive from the low rate of radiant heat transfer between the highly reflective aluminum surfaces while in a vacuum environment. Similar multilayer insulation covers the outside of the pressure vessel of the docking adapter, except that the insulation on the docking adapter is 91 layers thick, and is surrounded by the meteoroid shield and radiator. To be effective, multilayer insulation must first be evacuated to eliminate conduction between layers. Before launch, the insulation was purged with dry nitrogen, and evacuation took place during launch. Other kinds of thermal isolation help to control heat transfer locally. Fiberglass washers in the airlock insulate bulkhead fittings and cooling system components from supporting structures. Insulated clamps support some coolant lines, and coolant lines are wrapped with insulation.

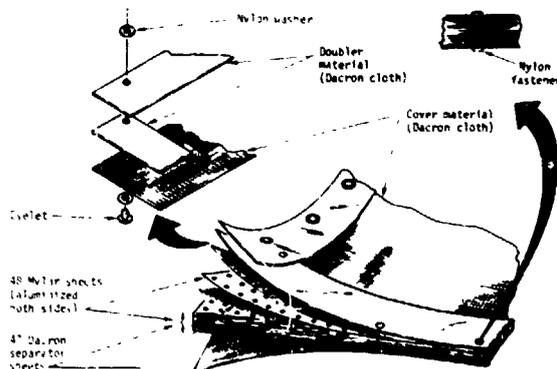


Figure 8-2.- Multilayer insulation.

Analyses indicated no significant change in properties of the polyurethane foam during the mission. Apparent heat losses to the waste tank from the workshop through the common bulkhead were less than predicted, which was partially the result of higher temperatures in the waste tank than had been anticipated. The airlock fiberglass curtains effectively limited heat transfer to the desired values, as indicated by acceptable wall temperatures. The inner surface of the docking adapter also remained at acceptable temperatures, indicating that the insulation was suitable. The thermal

conductance of the workshop insulation could be calculated using flight temperatures and calculated values of heat flux through the foam on the inner surface. The values determined at several points on the forward dome ranged from 0.0061 to 0.01 Btu/hr-ft<sup>2</sup>-°F, all less than the allowable maximum value of 0.02 Btu/hr-ft<sup>2</sup>-°F. The differences from estimated values were probably due to variations in the mechanical fasteners holding the insulation in place.

External surface coatings have two important thermal characteristics. The solar absorptance determines the fraction of incident sunlight (direct and reflected) which the surface absorbs; the infrared emittance determines the rates at which heat is radiated from the surface and gained by the surface from low-temperature sources (such as the Earth). Black, white, and aluminum paints cover all external surfaces of the workshop in a pattern (fig. 8-3) making the best use of the surface properties of the paints to control losses and gains of heat. Zinc oxide is the pigment in the two types of white paint used. One paint uses potassium silicate as a bonding agent, and the other uses a silicone material.

White paint using potassium silicate as a bonding agent is applied to the inactive side of the workshop solar array panels. When applied, this paint had a solar absorptance of 0.18 and an infrared emittance of 0.9. There was apparently no degradation of this paint. White paint using silicone as a bonding agent was applied to the last 3 feet of the workshop aft skirt and to part of the meteoroid shield surrounding the workshop.

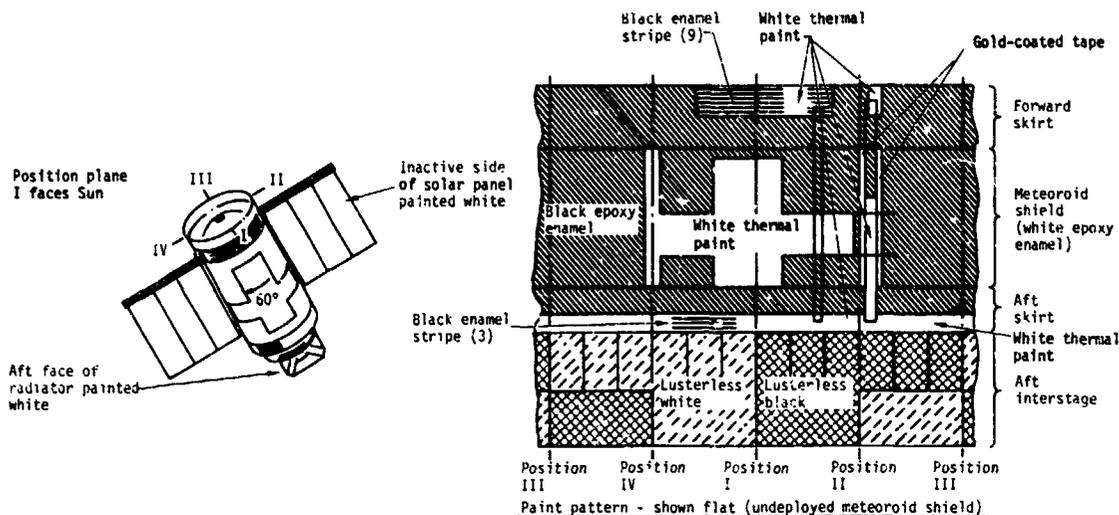


Figure 8-3.- Workshop external paint pattern.

The meteoroid shield that was to have protected the cylindrical part of the workshop was also to have served as a thermal radiation barrier. The workshop under the shield is wrapped with a gold-coated Kapton tape. Gold was selected because its low infrared emissivity, approximately 0.03 when applied, would limit radiant interchange between the workshop surface and the shield. Loss of the shield during launch exposed part of the gold surface to direct sunlight. The coating's solar absorptance was approximately 0.15, much higher than its infrared emissivity, so its equilibrium temperature would have been over 400°F in the solar inertial attitude. The surface suffered some damage from scraping by the meteoroid shield when it was lost, from impingement of exhaust gases from the separation retrorockets, and from aerodynamic and solar heating. Both the infrared emittance and the solar absorptance increased because of these effects. Estimates made from measured temperatures indicated final values of solar absorptance between 0.3 and 0.35 and infrared emittance between 0.06 and 0.1.

Temperatures in the workshop started to rise as soon as the Saturn Workshop reached orbit (fig. 8-4). As long as the gold surface was exposed, temperatures in the workshop could be limited only by increasing the incident angle of the sunlight. The Saturn Workshop was maneuvered as described in 3.2 to minimize problems until the first crew deployed the parasol thermal shield on Day 13. Mean internal temperatures began to decrease immediately from the 130°F maximum, and were stabilized in the 73 to 85°F range during the first manned period (fig. 8-5). The twin-pole thermal shield deployed on Day 85 provided enough additional surface coverage to decrease temperatures to a range of 71 to 76°F during the second manned period. Because of longer daylight orbits and a considerable number of experiment maneuvers which required rolling the shield away from the Sun, workshop temperatures ranged between 71 and 82°F during the third manned period.

There were some locations inside the workshop where temperatures could still have dropped low enough to cause condensation. Heat pipes, which require neither external power nor control, transport heat from warm places to these potentially cold spots. These pipes are sealed aluminum tubes containing freon and lined with a wicking material. Liquid Freon evaporates at the warm end and vapor condenses at the cool end. The condensate flows by capillary action to the warm end.

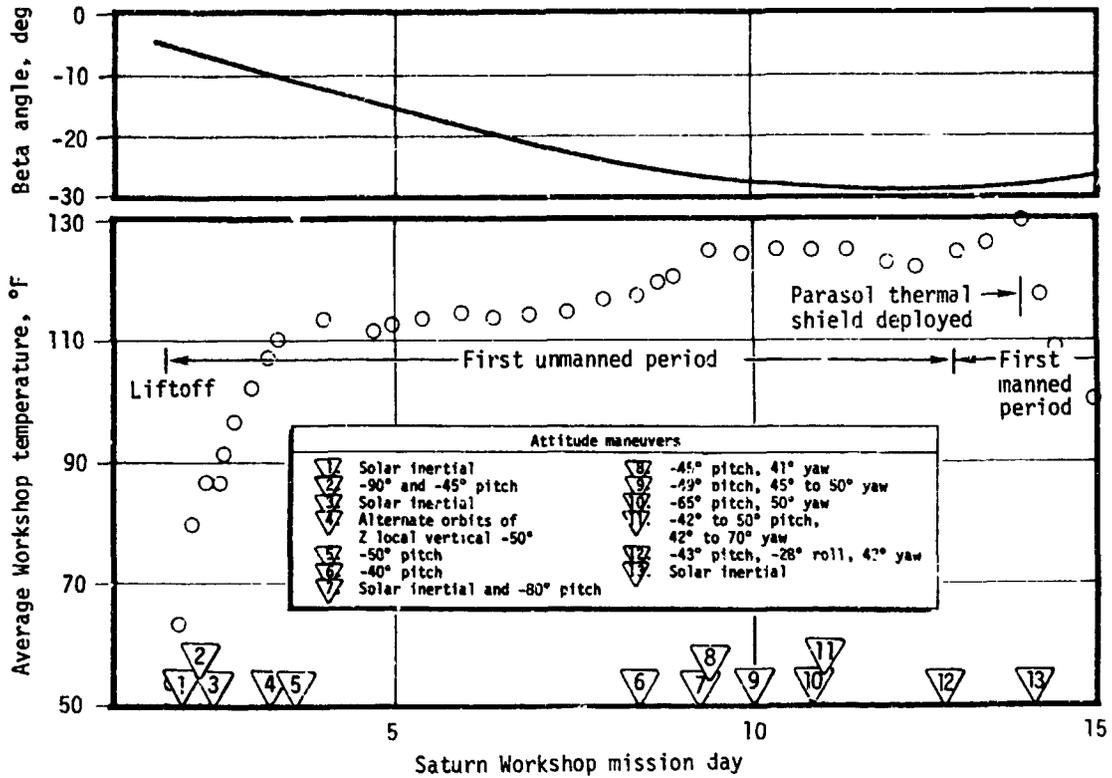


Figure 8-4.- Average workshop temperature through Day 15.

Since liquid and gas are at virtually the same pressure, they are essentially at thermal equilibrium, so a nearly uniform temperature prevails throughout the heat pipe. Loss of the meteoroid shield changed the temperature distribution near the heat pipes and prevented determination of their effectiveness.

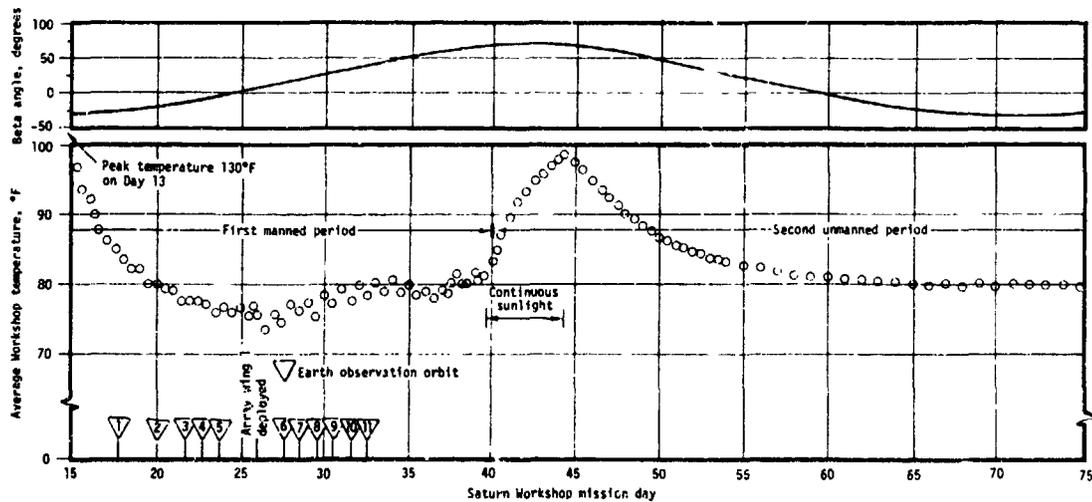


Figure 8-5.- Average workshop temperature from thermal shield deployment through Day 75.

## 8.1.2 Active Thermal Control

Heat from the walls and equipment, unless it is removed in some other way, enters the atmosphere of the laboratory. Part of the heat produced by the crewmen also enters the atmosphere directly, and the remainder enters in the form of water vapor. Redistribution of some of this heat and rejection of the excess heat is accomplished by the active thermal control system.

A low-viscosity silicone ester circulating fluid, Coolanol 15, transports heat from the interior to an external radiator through two independent, parallel, nearly identical loops, designated the primary and secondary cooling loops (fig. 8-6). The coolant flows through heat exchangers for cooling and dehumidifying the atmosphere, through cold plates attached to equipment, and through a radiator for rejecting heat to space. There are also additional heat exchangers in which the coolant removes heat from fluid used in auxiliary cooling loops that have no external radiators of their own. The coolant loops also include such necessary items as pumps and valves. Wax-filled thermal capacitors store heat during the daylight side of the orbit when the radiator outlet temperature is warmer than the wax in the capacitor. Either loop can furnish the required cooling, and critical items in each loop are duplicated to increase reliability and flexibility.

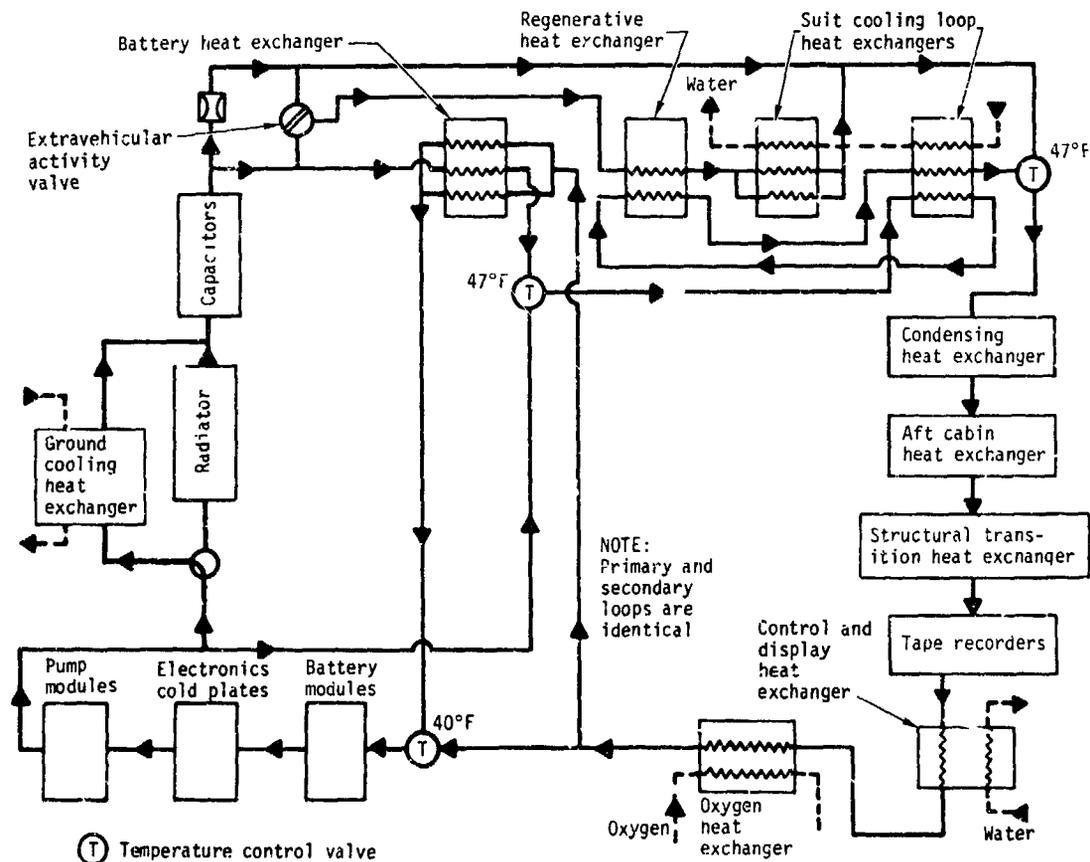


Figure 8-6.- Laboratory coolant loop.

Each coolant loop has three gear pumps plumbed in parallel which may be operated singly or in pairs. Three inverters are installed in each loop to provide the required alternating current. Each pump can be operated from either of two different inverters, and if two pumps are required in the loop they are operated from the same inverter. This increases the operating flexibility, since only

particular combinations of pump and inverter failures can make the loop inoperative. One pump is normally on in each loop, although two pumps may be used in a loop if one loop should fail. To meet specifications a single pump must deliver a flow of 230 lb/hr of coolant and two pumps must deliver 460 lb/hr. Reservoirs are also provided to maintain pump-inlet pressure and to provide an additional quantity of coolant should leakage occur.

The performance of the pumps during the mission exceeded specifications. Actual flowrates were 270 lb/hr for a single pump and from 510 to 520 lb/hr for two pumps. The Saturn Workshop was launched with one pump operating in the primary loop. When only one loop is in use, an automatic switching network can shut down the operating loop and start a pump in the other loop if either the temperature of the coolant or the pressure rise across the pump decreases excessively. Automatic switchover from the primary to the secondary loop occurred twice during the initial unmanned period. In neither case was the pressure or temperature, as reported by telemetry, low enough to cause the switchover. The problem appeared to be in the switching circuit, since the primary loop later operated successfully by using only one of the switching circuits. One pump in the secondary loop continued to operate until the first crew arrived. Thereafter, one pump in each loop operated during manned periods, except when conditions required a different mode of operation. The primary loop was shut down because of loss of coolant on Day 102 (8.4.1) and one pump in the secondary loop was operated for the rest of the second manned period. After recharging with Coolanol in the third manned period, one pump in the primary loop was operated along with one in the secondary loop except during extravehicular activity and during the period of maximum exposure to sunlight, when two pumps were operated in the primary loop and one in the secondary loop.

Valves at three points in each loop automatically control the temperature of the coolant. Each valve has an outlet port and two inlet ports, one for cold fluid and one for warm fluid. A movable sleeve regulates the flow entering the inlet ports, admitting more or less warm or cold fluid. Two valves are set to give an outlet temperature of 47°F. The first of these valves controls the flow to the radiator. Fluid leaving the pump flows either to the radiator or to the warm inlet port of this valve, and some of the fluid passing through the radiator then flows to the cold inlet port of this valve. The control valve mixes these two streams to give an outlet temperature of 47°F. This valve in each loop operated satisfactorily throughout the mission. The coolant then flows from this valve to the warm inlet port of a second valve which keeps the temperature of the coolant entering the condensing heat exchangers at 47°F. Problems occurred with these valves in both loops beginning on Day 25, and necessitated changing procedures used during extravehicular activity (8.4.1). The third valve regulates its outlet temperature to 40°F. As the cold inlet port of this valve opens, it allows part of the upstream coolant flow to be diverted to a heat exchanger, where it is cooled by cold fluid from the radiator. The capacity of this valve to control its outlet temperature is limited by the amount of cold fluid demanded by the 47°F valve at the condensing heat exchanger inlet. On Day 4, when only the primary coolant loop was operating, the discharge temperature rose to 45.7°F at a time when equipment being cooled by the fluid was operating at very low power. To avoid freezing coolant inside the radiator, additional equipment was turned on. A result of the additional heat load was reduction of the temperature of the fluid leaving the valve to less than 42°F. This valve operated satisfactorily throughout the mission.

Fluid in the coolant loop rejects heat to space as it flows through an external radiator located on the outside of the Saturn Workshop. The radiator,

with a total surface area of 432 ft<sup>2</sup>, has 11 panels made by welding magnesium skins to extruded magnesium sections containing flow passages. The exposed surface is painted white. During the daylight side of the orbit, heat is stored in a thermal capacitor which consists of honeycomb boxes that are filled with tridecane wax and have integral cold plate flow passages (fig. 8-7). Fluid from both coolant loops passes through each plate. Tridecane's heat of fusion is 66 Btu/lb and it melts at 22°F, making it an effective material for absorbing heat. Before launch it is cooled well below its freezing point, and it absorbs all of the launch heat loads that have to be dissipated by the coolant until the shroud is jettisoned. Coolant flows from the radiator directly to the flow passages in the thermal capacitor. During the dark part of each orbit, when the radiator can reject heat to space, the outlet of the radiator is cold. Coolant passes through the thermal capacitor, cooling the tridecane, and is still cold enough to satisfy the cooling requirements. When the Skylab is on the daylight side of the Earth, the radiator outlet is warmer than the capacitor, so it transfers a portion of its heat to the tridecane.

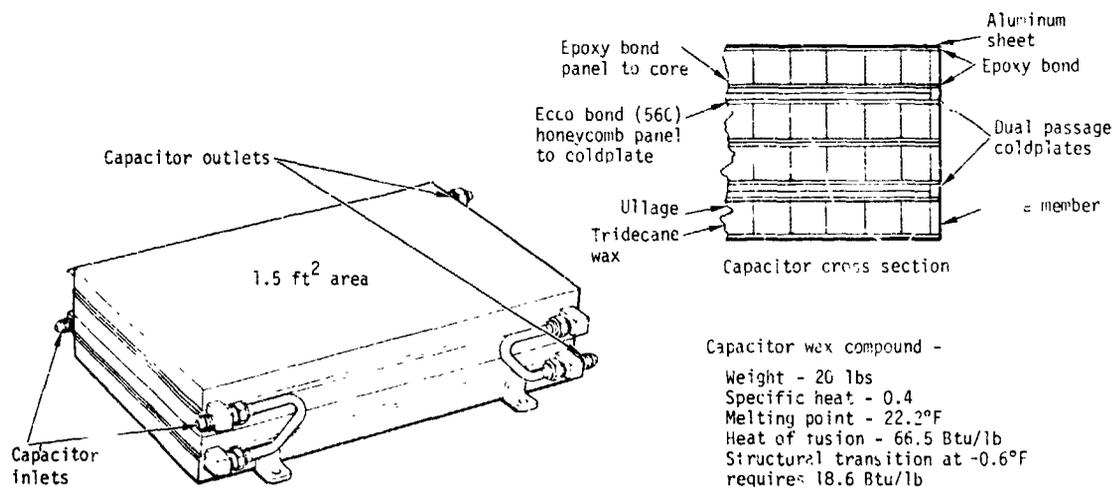


Figure 8-7.- Thermal capacitor.

The radiator heat loads were generally so low that all of the tridecane remained frozen at the end of the orbital day. As the orbital plane shifted so that the length of the orbital day increased, some of the tridecane melted. All of the tridecane in the thermal capacitor was melted when Skylab was oriented to allow Earth observations during a time of maximum orbital daylight in the third manned period. As expected, coolant temperatures exceeded their specified values for a short time, but not long enough to cause any problem. The capacity of the radiator was more than adequate for the greater part of the operations. Also, as expected, the white paint on the radiator surface deteriorated somewhat during the mission. Its solar absorptance, as calculated at the end of the mission, had increased to 0.25 from its initial value of 0.14, although the infrared emittance did not change from its initial value of 0.85. The crew reported noticeable discoloration of the part of the radiator that was exposed to sunlight. The discolored section probably had a larger increase in absorptance than the part not exposed to sunlight, and the value calculated from the rates at which heat was dissipated reflected the average amount of degradation.

The cooling system's capacity exceeded demands both for cooling individual units and for dissipating heat to space. The maximum allowable temperature of the coolant at the pump discharge was 120°F. The maximum temperature at this point during the mission was 75°F, indicating a comfortable margin; all the equipment remained at satisfactory temperatures throughout the mission. The

temperature at the pump discharge reflected the total amount of heat which had to be dissipated. Again, there was a satisfactory margin of capacity. The system was designed to reject up to 16,000 Btu/hr, but the maximum heat load at any time during the mission was just over 12,000 Btu/hr. The excess capacity made possible continued operation when the loss of coolant forced operation of only one coolant loop for part of the second manned period (8.4.1).

## 8.2 AUXILIARY SYSTEMS

The auxiliary thermal control systems are those subsystems provided to remove heat from certain components. The suit cooling system and the equipment cooling system have a heat interchange with the primary laboratory cooling system and require its operation for heat rejection. These two systems use water with a corrosion inhibitor and biocide as the cooling medium. The refrigeration system, which has no connection with the primary laboratory cooling system, provides cooling for the food and waste management system freezers and chillers.

### 8.2.1 Suit Cooling

Cool water flows through the liquid-cooled garments worn by the crewmen under their spacesuits from either of two identical, parallel loops (fig. 8-8). The water in each loop is cooled in a heat exchanger by transferring the water's heat to the coolant flowing through the primary laboratory cooling system. Each water loop has two pumps, a reservoir containing the water supply (pressurized to 5 psia with nitrogen), and a separator to remove gas from the circulating water. The possibility that gas could leak into the tubing in the liquid-cooled garments and become entrained in the water led to the inclusion of the separator. Since weightlessness prevents the separation of gas from liquid through the use of differences in density, a technique based on surface characteristics is used. Inside the separator are two filters, one wettable by water and the other non-wettable. The water entering the separator passes through the wettable filter. The other filter surface remains dry, and any entrained gas passes through it. The separators performed satisfactorily throughout the mission.

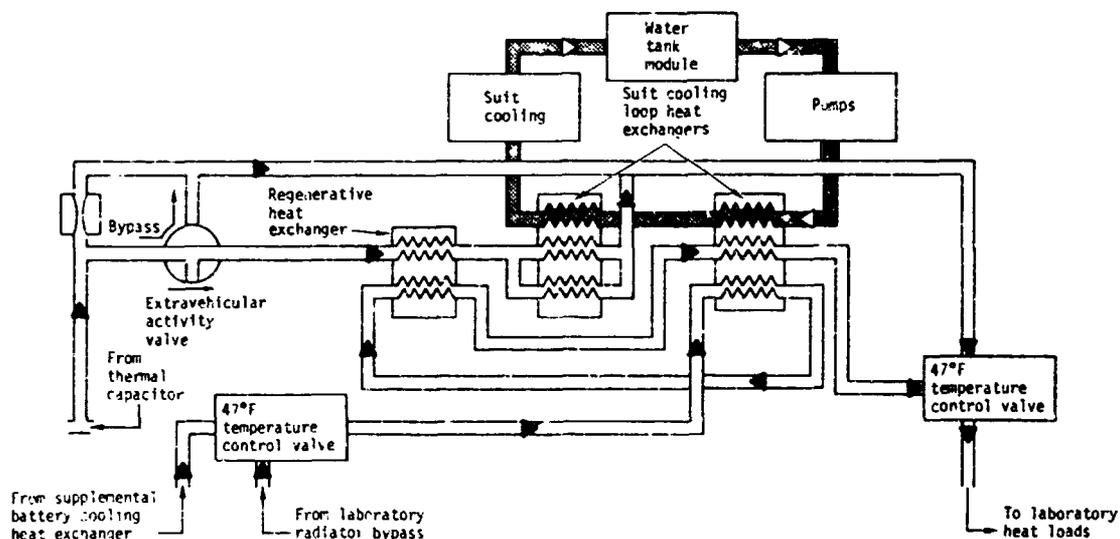


Figure 8-8.- Suit cooling system.

Although external events affected the performance of this system, it was generally adequate. Twice during the mission, water leaked from the composite

connector that attaches to the space suit. Leakage first occurred during an extravehicular activity on Day 226, and enough water was lost to require that the crew transfer water to the reservoir. Leakage also occurred during the last extravehicular activity, with loss of most of the water from the reservoir. A flowmeter became erratic during the second extravehicular activity of the first manned period and eventually indicated no flow. Subsequently, it behaved satisfactorily, with no further indications of improper operation.

Attitudes used during the initial unmanned period to reduce temperatures in the workshop also reduced the temperature in the vicinity of this water system. The possibility that the water might freeze was a major concern, since freezing could rupture the water lines. Freezing was averted by changing the attitude of the Saturn Workshop to allow more solar heating in the vicinity of the water system. The lowest temperature was between 31.5 and 33.5°F, depending on the accuracy of the measurement. It is believed that no freezing occurred, since there was no evidence of damage.

Use of these water loops during the mission was not as planned. The first time that coolant in the laboratory cooling system was switched to allow flow through both suit-cooling heat exchangers, the temperature-control valves in the laboratory cooling loops stuck in a position that allowed excessive flow of cold coolant through the heat exchangers. The coolant was switched back, and, to prevent further difficulties, coolant was circulated through only one of the heat exchangers for other extravehicular activities (8.4.1).

### 8.2.2 Equipment Cooling

A single water loop (fig. 8-9), capable of removing 1437 Btu/hr including 102 Btu/hr from the circulating pump, cools the Earth observation equipment

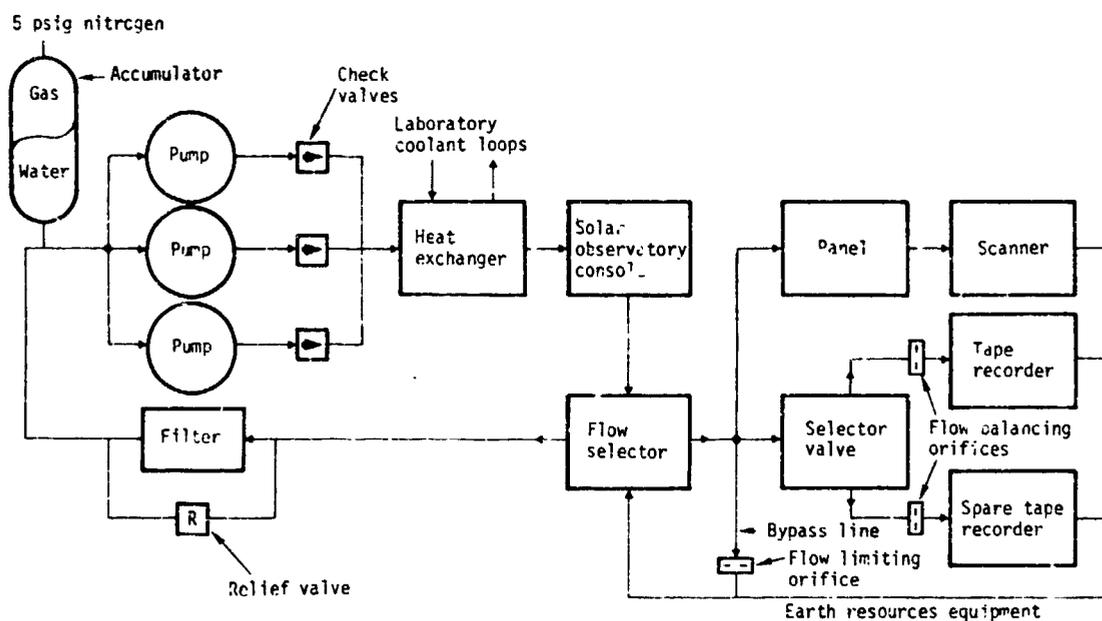


Figure 8-9.- Equipment cooling loop.

and the solar observatory console in the docking adapter. The loop has three positive-displacement, rotary-vane pumps in parallel, although one pump is enough to provide the necessary water flow of 220 lb/hr. Each pump has a relief valve to bypass flow to protect the pump if the downstream flow path is blocked, and has a

check valve in the discharge line to prevent backflow when the pump is not running. A heat exchanger having parallel flow paths to accommodate coolant from both laboratory cooling loops maintains the water below 78°F. A tank containing about 12 pounds of water is pressurized with nitrogen to 5 psia to maintain pump inlet pressure and to provide additional water in the event of leakage.

Despite a problem with gas (8.4.1), this system fulfilled its functional requirement to maintain temperatures of the equipment it serviced within specified values. Analysis showed that the equipment would be cooled sufficiently if the water inlet temperature did not exceed 78°F; the maximum inlet temperature measured was 74.9°F. Heat loads appeared to be greater than expected, partly because of unanticipated heat leaks into the system and greater than expected conductances between the equipment to be cooled and the water. During an Earth observation pass on Day 252, the heat load reached a maximum of 2780 Btu/hr. This condition lasted only a short time and produced no adverse effects. When the crew replaced a filter on Day 15, they reported that the internal plunger in the quick-disconnect fitting did not close fully when the fitting was removed. This was only a momentary malfunction, and leakage did not recur when the filter was again replaced on Day 32.

### 8.2.3 Refrigeration

Refrigerated storage of food was a major innovation of the Skylab program. There are five insulated compartments for storing frozen food and a chiller for thawing frozen food and storing leftovers (10.1.6). A coolant circulating through these compartments keeps the contents cold. The refrigerant is Coolanol 15 (also used in the laboratory cooling system). It also chills water for drinking, chills and freezes urine and blood samples, and cools the pump power supply. It circulates through two independent, parallel loops (fig. 8-10), designated primary and secondary, either of which can satisfy all requirements for refrigeration. The loops share a common radiator and a common thermal capacitor. Four pumps are available for circulating the coolant in each loop. Only one pump operates at a time, so one loop is in operation at any time. The pumps are in a sealed enclosure that is vented to the waste tank to ensure that any refrigerant leaking from the pump does not enter the habitable volume.

There are two pump packages for each loop. Each package contains two positive-displacement gear pumps (each having its own power supply), an accumulator, a relief valve, and a check valve in the discharge line. If the pressure rise across the pump exceeds 100 psi, the relief valve opens, letting refrigerant return from the discharge line to the pump inlet. Freon acting on a bellows in the accumulator ensures a constant base pressure in the coolant loop. These pumps had been qualified for 2250 hours, not long enough to allow completion of the mission. This motivated a sequence for turning pumps on and off, either manually after fixed operating times or automatically in response to conditions indicative of the performance of the pumps. A differential pressure below 25 psi across the operating pump causes that pump to be turned off and the next pump in the sequence to be turned on. If the operating pump is the fourth pump in either loop, the first pump in the other loop is turned on. Any one of four other conditions causes the operating pump to be turned off and the first pump in the other loop to be turned on: less than 5 in.<sup>3</sup> of refrigerant in the accumulator for both pump packages, a temperature of 1°F at the inlet to the frozen-food compartments, a temperature of 33.5°F or less at the inlet to the chillers, or a logic power supply voltage beyond  $5.0 \pm 0.45$  volts.

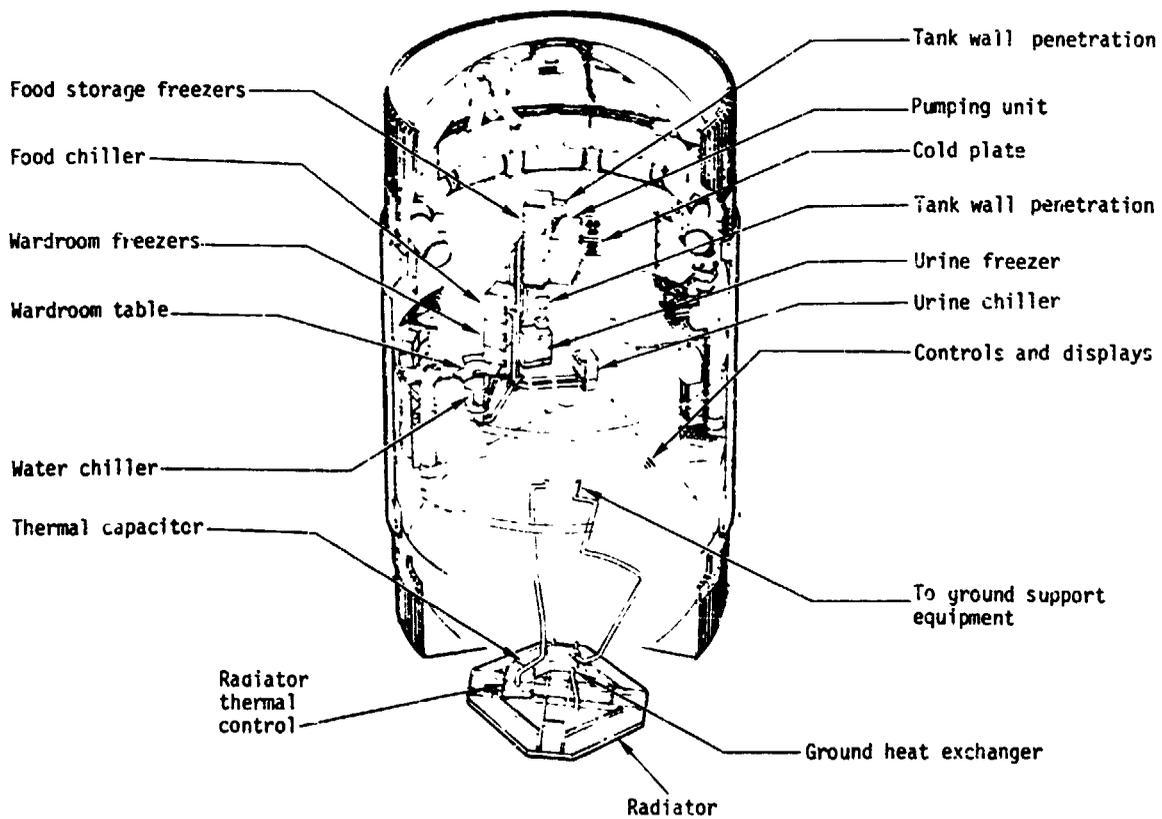
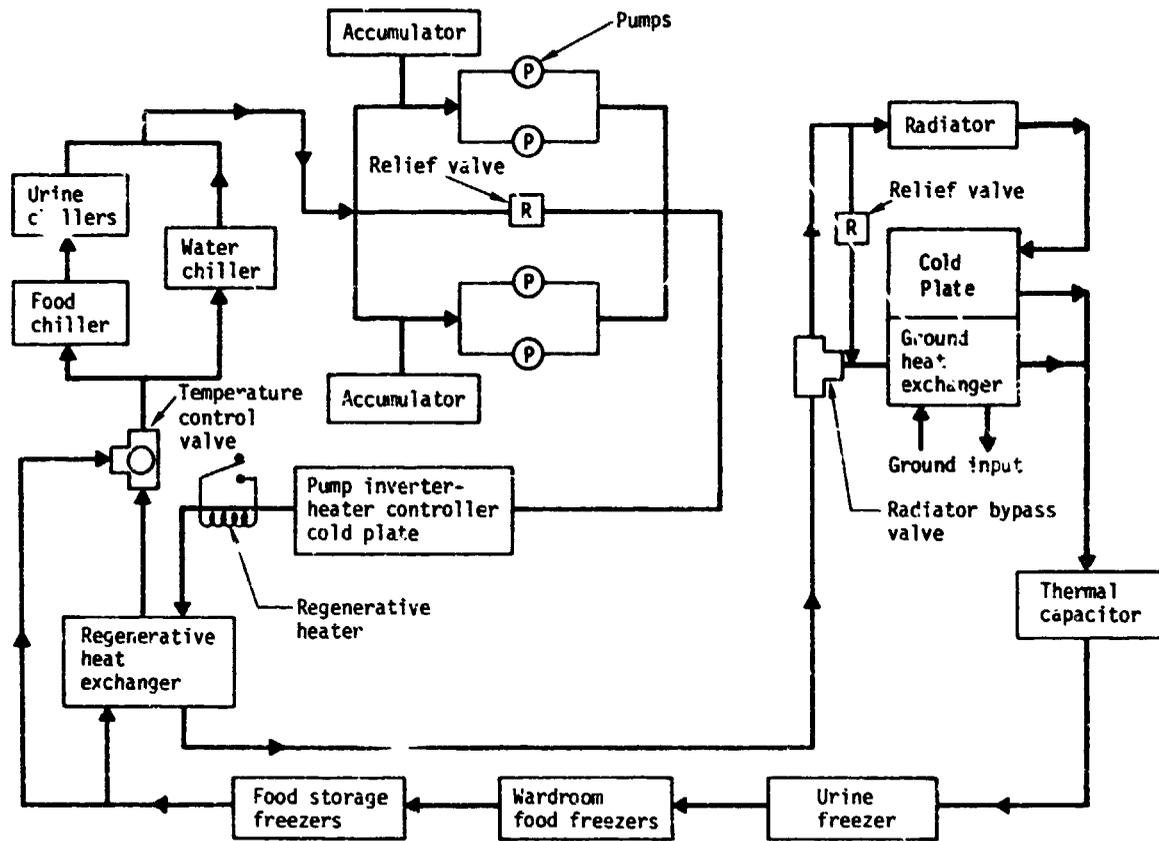


Figure 8-10.- Refrigeration system (other loop identical).

One pump in the primary loop was turned on 24 days before launch, in preparation for loading frozen food. This pump continued to run until Day 27. Then, in accordance with the plan, it was turned off, and the second pump in the primary loop started. The changeover from one pump to the other was smooth, with no interruption of flow. A valve malfunction not associated with the pumps led to unplanned operations on Day 40 (8.4.2). The first pump was cycled 105 times, and then it ran continuously until the end of the mission, for a total operating time of 7270 hours. The second pump in the primary loop operated for 300 hours. One pump in the secondary loop operated for 369 hours, of which only 2 hours was in orbit; during a period of trouble-shooting, this pump was cycled 28 times. These three pumps operated satisfactorily, and one of them demonstrated that the qualified lifetime was conservative. The other pumps were never operated during the flight.

The refrigeration system radiator, located at the aft end of the Saturn Workshop, rejects heat gained by the coolant. An octagonal shape was chosen to maximize the surface area and still provide the necessary clearance between the radiator edge and the interstage structure during separation. The radiator is canted 5 degrees so that sunlight does not strike the surface directly while in the solar inertial attitude. For analyses, the white paint on its surface was assumed to have a maximum degradation corresponding to a solar absorptance of 0.25 and an infrared emittance of 0.887. A shield protected the radiator surface until the Saturn Workshop reached orbit. After an hour, the temperature of the radiator became low enough for coolant flow to be started through the radiator. The material in the thermal capacitor had completely refrozen after an additional 2 hours, and the temperature of the coolant was low enough 95 minutes later to allow bypassing the radiator. The subsequent performance of the radiator was excellent.

The rate at which the coolant gains heat varies with temperatures in the workshop. Therefore, when the meteoroid shield was lost and temperatures in the workshop rose to 130°F during the initial unmanned period, the radiator had to dissipate as much as 2000 Btu/hr. However, the coolant remained cold enough throughout this period to keep the warmest frozen-food compartment below the specified minimum temperature of 0°F. After the first crew arrived and turned on more equipment, including ventilating fans, the amount of heat to be dissipated increased somewhat and the temperature of the warmest compartment rose to 0.5°F. Thereafter, as temperatures in the workshop decreased, the radiator was never a limiting factor in meeting the requirements for refrigeration.

Cold coolant flows to a thermal capacitor from the radiator, after passing through a cold plate attached to an inactive ground heat exchanger which somewhat moderates change in the temperature of the fluid entering the thermal capacitor. The thermal capacitor stores heat during the daylight side of the orbit. It consists of three units in series. Each unit consists of two rectangular honeycomb structures separated by a plate containing separate flow passages for coolant from both loops. The honeycomb structures are filled with undecane, a wax that freezes at -14.5°F. Before launch the undecane was cooled to about -26°F, and for the first hour after the Saturn Workshop reached orbit the thermal capacitor absorbed all the heat picked up by the coolant. After the radiator outlet temperature dropped below 0°F, the flow was automatically switched to the radiator. The thermal capacitor continued to perform satisfactorily for the whole mission. Its capacity to absorb heat was adequate for normal operation, and there was enough heat transfer to cool the undecane as rapidly as necessary and to cool the coolant to the desired temperature.

In addition to the pressure-relief valves on the pump packages, there is also a pressure-relief valve in each loop to protect the radiator. Should the refrigerant flowing through the radiator become cold enough for its increased viscosity to cause a pressure drop greater than 34 psi across the radiator, the relief valve opens and allows refrigerant to bypass the radiator. No condition requiring this valve to open occurred during the mission.

A two-position, solenoid-operated valve in each loop controls the temperature of the coolant. If either of two independent conditions exists, the coolant bypasses the radiator and flows directly to the thermal capacitor. One condition is high temperature of the radiator surface. If this temperature rises to 15°F, coolant flow bypasses the radiator, and flow through the radiator resumes only if the temperature decreases to 0°F. The other condition is low temperature of the coolant leaving the first unit of the thermal capacitor: a decrease to -34.5°F causes coolant flow to bypass the radiator, and an increase to -12.8°F causes flow through the radiator to resume. Improper operation of these valves beginning on Day 40 constituted the only problem associated with the refrigeration system (8.4.2).

The coolant flows from the thermal capacitor to the urine freezer and the compartments for storing frozen food. Then some or all of it may pass through a regenerative heat exchanger in which it is warmed to a temperature compatible with the requirements of the food chiller, urine chiller, and water chiller. From the chillers, the coolant flows to one of the four pumps in the loop.

Flow of cold coolant through the regenerative heat exchanger is controlled by a valve that mixes cold fluid and warm fluid as needed to give the required temperature. The valve has inlet ports for warm fluid from the heat exchanger and for cold fluid that bypasses the heat exchanger. An element inside the valve expands or contracts as the temperature of the discharge stream increases or decreases from its set point of 39°F, varying the relative open areas of the hot and cold inlet ports. This valve performed well throughout the mission, maintaining a nearly constant discharge temperature at all times. If the temperature from the heat exchanger going to the valve decreases below 37°F an electric heater warms the coolant entering the regenerative heat exchanger.

Overall performance of the entire system was excellent, despite the difficulties with the bypass valves. The frozen food was kept in good condition throughout the mission. There was a moderate buildup of frost on the surface between the doors. The crew commented on the necessity of removing the frost periodically, although removing it was not difficult. The temperature of the urine chiller remained below 46°F throughout the mission, less than the 59°F upper limit that was specified. The freezer for samples of urine and blood stayed cold enough to meet the requirement of cooling samples below 30°F within 90 minutes and below -2.5°F within 8 hours. No leakage of coolant was detected.

### 8.3 SOLAR OBSERVATORY THERMAL CONTROL

The solar observatory was originally designed for independent operation and so it has an autonomous system for controlling temperatures. To regulate temperatures satisfactorily required independent consideration of each of the three major divisions of the solar observatory: the instruments, the instrument canister, and the rack (fig. 8-11). The rack electrical and mechanical components are thermally controlled within desired temperature limits by means of a combination of selective equipment placement, radiation shielding, low conductance mountings, insulation, surface coatings, and, for some components, thermostatically controlled

heaters. The instrument canister uses an active liquid heat transport loop to maintain a near-constant temperature environment for the experiments. The individual experiments use passive thermal control techniques in conjunction with thermostatically controlled heaters to satisfy the stringent temperature requirements dictated by optical considerations.

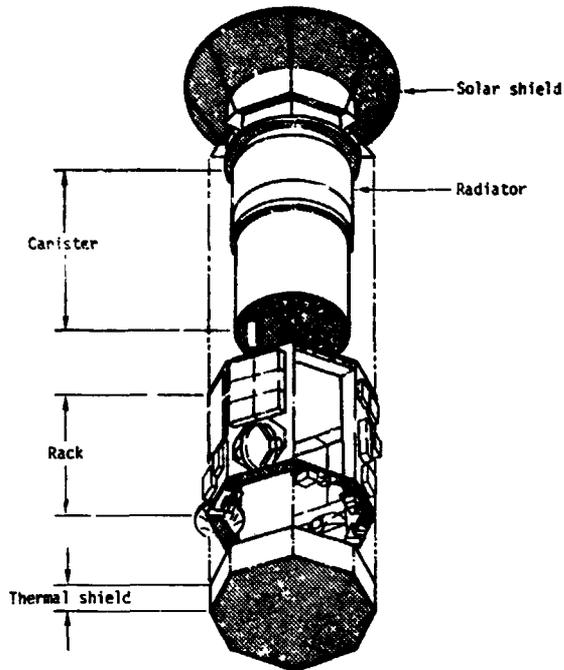


Figure 8-11.- Solar observatory expanded view.

A fluid circulates to keep the inner surfaces of the canister at a nearly constant temperature. The flow is divided between the two halves; in each half, the fluid, a mixture of methanol and water containing 80 percent methanol by weight, flows through all the passages consecutively. At the design flowrate of 850 lb/hr, the temperature of the fluid increases 5°F when equipment in the canister is operating at a total power of 500 watts.

Multilayer insulation covers the outer surface of the canister, including the end facing the Sun. There is an aperture through the insulation in line with each of the solar instruments in the Sun end of the canister. Doors covered with multilayer insulation seal the opening of each aperture when the instrument is not in use. The 10-inch overhang at this end of the canister keeps sunlight from falling directly on the radiator panels mounted around the circumference of the canister. The radiator panels are part of the heat-transfer loop (fig. 8-12). Four panels containing integral flow passages provide a total radiating area of 80 ft<sup>2</sup>. At the designated operating temperature, the radiator can reject 500 watts. The radiator and a heater section provide alternate flow paths for the fluid. For less cooling, some or all of the fluid is diverted to the heater section, which has two heating elements of 250 watts each. If the temperature of the fluid falls below 47.7°F, the first heating element turns on automatically. A further temperature decrease to 47.0°F activates the second heating element. An increase in the fluid temperature to 48.5°F causes the heating elements that are operating to be turned off.

The rack is an open assembly of trusses forming a structure of octagonal cross-section that completely surrounds the canister. It serves as a mounting for approximately 140 electrical and mechanical components, including control gyros, control computers, rate gyros, batteries, and Sun sensors. These components generate heat when operating and are also heated by thermal radiation from the Earth and the Saturn Workshop and by reflected sunlight, although an annular shield protects them from direct sunlight. The components that generate the most heat are around the outside to enhance heat rejection. Low-heat-generating components are located in bays which are covered with radiation shields and mosaic multilayer insulation to control heat rejection. If necessary, components are furnished with thermostatically controlled heaters.

The top and bottom halves of the canister are each made of eight plates containing internal passages through which a

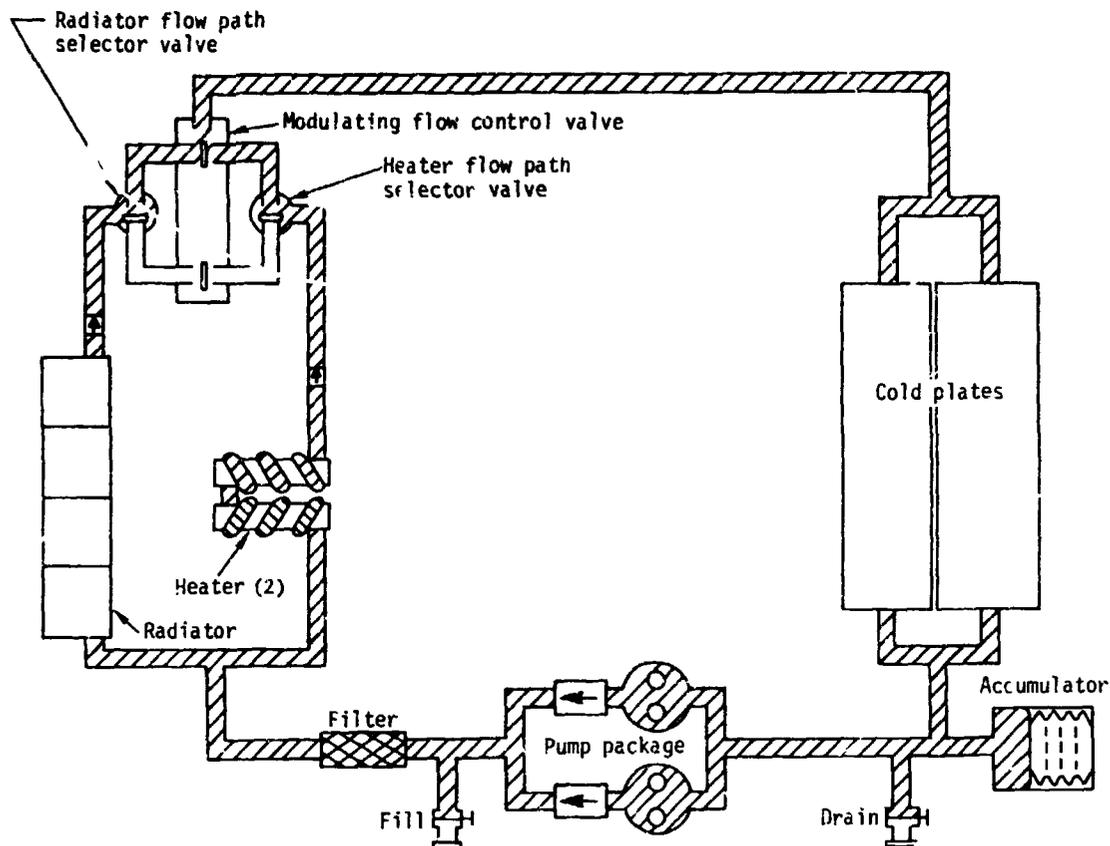


Figure 8-12.- Solar observatory coolant loop.

Inside the canister and dividing it into quadrants is the spar, a cruciform structure that supports the solar instruments. Multilayer insulation covering the aluminum spar assists in maintaining a uniform temperature. To isolate the spar and further minimize temperature gradients that might cause misalignment of optical instruments, the structural connections between the spar and the canister have low thermal conductance.

The temperatures of the eight solar instruments mounted on the spar must be controlled precisely, since even small variations in temperature would affect the pointing stability and the focusing characteristics of the instruments. The housings are made of materials of high thermal conductivity to minimize temperature gradients. Low-conductance mounts minimize heat conduction between the instruments and the spar, so radiation is the dominant mode of heat transfer between these and other surfaces. The inner surface of the canister is black to maximize interchange of thermal radiation between this surface and the instruments. Insulation and surface coatings on the instrument housings control the rates at which heat is radiated and absorbed. Two of the eight instruments generate heat at a low rate which requires a gold coating on the surfaces to obtain the necessary low emissivity. The other instruments generate heat at higher rates when they are operating and require higher surface emittances to radiate the heat away at the desired temperature. The high emittance, however, allows the instrument to radiate away too much heat when it is not in use. To prevent this, electric heaters are used. In some cases, the heater is incorporated in a radiation shield that completely surrounds the instrument without touching it. The

heater turns on and off when the shield is 0.5°F below or above a fixed temperature. The radiation shield has very low thermal capacity, so its temperature fluctuates rapidly between the two extremes, presenting a nearly constant radiation environment to the instrument. In other cases, the heating element surrounds and is attached to the housing of the instrument. Some of these heaters operate intermittently on demand, while others operate continuously, and the power supplied to them varies with demand.

The orientation of the Saturn Workshop that proved most effective in controlling temperatures in the workshop during the initial unmanned period created thermal problems for the solar observatory, since it exposed to direct sunlight parts of the rack that would normally be in the shadow of the solar shield. Concurrently, available power was drastically reduced. This mode lasted from shortly after the Saturn Workshop reached orbit until the first crew deployed the parasol thermal shield. Temperatures of some components on the rack approached their upper limits and, in the case of a power conditioner and a tape recorder, exceeded them. Increased demand while temperatures were generally high caused both these problems.

Because of the shortage of electrical power, the heat-transfer loop was not activated immediately, and the use of electric heaters was restricted. Before launch, the canister had been purged with a continuous flow of dry nitrogen at controlled temperature to maintain constant temperature and humidity around the equipment in the canister. Consequently, the canister and the equipment inside it were at 69.5°F at launch. About 25 hours later, the electric heater for one telescope in each quadrant was activated. Operating these four heaters kept the instruments from becoming too cold; the lowest temperature was 53°F, within the allowable range of 40 to 85°F.

The heat-transfer loop and all heaters were activated after temperatures in the workshop returned to normal and Skylab had returned to the solar inertial attitude. The temperatures of the instruments stabilized approximately 20 hours later. The spar, however, because of its mass and the low rate of heat transfer between it and the canister, required several days to reach a stable condition. The heat-transfer loop and the heaters were turned off for 14 hours on Day 25. This action had only a slight effect on temperatures. The instruments reached stable temperatures in 5 to 10 hours, and the spar after approximately 14 hours. The specified temperature of the fluid entering the cold plates is 50 ±3°F; actual values during the mission were between 48 and 51°F.

Temperatures were controlled satisfactorily throughout the second unmanned period. Leaving one of the experiment aperture doors open continuously during unattended operations resulted in temperatures in that instrument increasing to within 0.4°F of the upper limit. Mechanical problems with other aperture doors eventually required that four doors be left open permanently. This had no significant effect on the temperature of the canister or the instruments until Days 247 through 250, when Skylab was in continuous sunlight. During this time, temperatures of parts of some of the instruments and of the spar exceeded their maximum allowable values. Although these temperatures were higher than anticipated, they were not high enough to cause damage.

Since only the primary pump had been used for the entire mission, it was shut down during postmission testing, and the secondary pump was turned on for

testing. After it had operated for a short time, it was shut down and the primary pump restarted. The primary pump had 305 hours of preflight and 6154 hours of flight operations. There were no problems associated with either pump.

The crews reported discoloration of the white paint used on all the exposed surfaces of the solar observatory. This paint originally had an infrared emissivity of 0.9 and a solar absorptance of 0.22. Analysis based on measured surface temperatures showed a solar absorptance of 0.53 at the end of the mission, as compared with the predicted 0.35 based on premission tests. The greater degradation occurring during the mission is unexplained and is still under investigation.

#### 8.4 ANOMALIES

##### 8.4.1 Laboratory Coolant Loops

Temperature Control Valves.- The 47°F valve at the inlet to the condensing heat exchangers stuck during the first extravehicular activity on Day 25 when the extravehicular activity valve in the primary laboratory cooling system (fig. 8-6) was switched to allow coolant from the capacitor to flow through the second suit cooling heat exchanger. Diverting coolant so that it passed through this heat exchanger initially increased the temperature at the cold part of the 47°F valve, which reacted in the expected manner by moving to the full cold-flow position. The valve then should have returned to an intermediate position to control the outlet temperature to 47°F. However, as the valves in both the primary and secondary loops traveled back toward the intermediate position, they stuck in a position that provided excessive cold flow. This is thought to have occurred as a result of contamination released in the system when the extravehicular activity valve was put in the extravehicular activity position. The immediate result was that the water in the suit cooling loop (which interfaces with the primary loop) apparently froze. In attempting to reactivate the primary coolant loop later, the condensate in the condensing heat exchangers also apparently froze, causing the molecular sieve compressor flow to stop. Adequate cooling was provided for the extravehicular activity, and deploying the workshop solar array was completed successfully by using the secondary coolant loop and one suit cooling loop to cool all three crewmen. When the load was removed from the suit cooling loop, the outlet temperature of the 47°F valve in the secondary loop decreased since it was also stuck. It later decreased to approximately 30.7°F, causing concern regarding a possible freezing in the condensing heat exchangers again. The crew was asked to reactivate the suit cooling loop and place the liquid-cooled garments near a water tank on the hot side of the workshop. This added enough heat to raise the outlet to 40°F.

Later, both valves were freed by allowing the valve sensor cartridge to warm up until the expansion of the cartridge freed the valve. To preclude a recurrence of the same problem, the extravehicular activity valve was left in the bypass position continuously. It was found that cooling capabilities were adequate in this mode. In the second manned period, when inadequate coolant was available due to leakage in the primary loop, one extravehicular activity was accomplished by using a high flowrate of oxygen for cooling. The second crew carried along a heater, which was designed and built during the unmanned period, to heat the water in the suit cooling system should it be required. A valve did stick on a later occasion, but the resulting temperatures could be tolerated so the heater was not used.

Leakage.- On Day 84, a primary loop accumulator low limit warning occurred. There was no way of measuring directly the amount of coolant in either loop, but an analysis of the pressures, temperatures, and volumes showed slow leakage in both the primary and secondary loop. Calculations showed the leakage from the primary loop to be from 0.08 to 0.12 pound of coolant each day. Pressure at the pump inlet also showed a consistent decrease. The pump inlet pressure on Day 84 was still high enough to prevent cavitation (less than 3 psia in tests), so the pump was allowed to continue running. By Day 102, the pump inlet pressure was oscillating and had decreased to 5.8 psia. Should cavitation have occurred, it could have become serious enough to damage the pump, so the primary loop was shut down. The secondary loop provided all cooling from that time until the primary loop was recharged in the third manned period. During the third unmanned period when only the secondary loop was operational, its coolant leaked consistently at a rate of 0.09 lb/day.

Attempts to locate the leaks were unsuccessful. The primary loop appeared to be leaking both inside and outside the habitable volume, since pressure in the loop followed internal pressure but remained below it during the third unmanned period when the reservoirs were depleted. Analysis of returned cartridges from the carbon dioxide sensors indicated that some coolant may have been in the gas entering the molecular sieve assembly. Coolant was also found in charcoal filter canisters that were returned for analysis.

The third crew refilled the primary loop with coolant on Day 190. A re-servicing kit consisting of a saddle valve and a tank, developed after leakage became apparent, was flown up for this purpose. The saddle valve is an assembly which fits over the coolant line to provide a tight seal so that a built-in cutter can puncture the line. With the valve open, coolant was forced into the line by applying pressure to a bellows in the supply tank. After fluid was added to it, the primary loop was restarted and continued to operate satisfactorily for the rest of the mission. No further addition of coolant was necessary. The pump inlet pressure in the secondary loop did continue to decrease, and a warning of a low level in the reservoir occurred on Day 271 during the last deactivation. If necessary, coolant could have been added to the secondary loop.

Equipment Cooling.- One of the pumps in the equipment cooling loop was turned on during activation on Day 15, but it gave a flowrate that oscillated between 240 and 305 lb/hr. The crew turned off the pump, changed the filter, and restarted the pump. The flowrate was steady at 244 lb/hr. The crew reported a gurgling sound in the water loop on Day 132, and later the flow decreased to 74 lb/hr. After shutting the pump down and changing the filter the crew turned on a second pump, which provided a stable flow of 231 to 234 lb/hr. The filter was returned for analysis but showed nothing unusual.

Later, the second pump displayed similar tendencies, with the flow decreasing from 245 to 165 lb/hr on Day 190. A series of tests made on the ground eliminated several possible causes of the problem. The second pump was turned off, and the third pump was used until it exhibited a low pressure rise and a reduction in flow. It then appeared that the most likely possibilities were gas mixed with the water, and debris in the pump. The crew removed the filter and inspected it, finding only a small amount of debris. They noticed gas when they opened the quick-disconnect fitting. A spare liquid-gas separator for the suit cooling loop was installed in place of the filter. Both the second and third pumps operated stably with the separator in the line. The separator was removed, and operation

continued with a gradual decrease in flow and only occasional flow oscillations for about 15 days. The crew again installed the liquid-gas separator for a time, and the flow again became normal for a while. The problem did not become serious enough before the end of the mission to warrant further action. Near the end of the mission the first pump was turned on, and it appeared to operate normally, giving a further indication that the problems resulted largely from gas in the system.

Inverter.- On Day 16, secondary inverter 1 and pump A were turned on by ground command. The inverter circuit breaker opened immediately, so the crew switched to another inverter and pump combination. Lack of data at the time precluded determination of the cause, so the failed units were not used again during the mission. However, troubleshooting procedures were developed for use if all the other pump and inverter combinations should have failed. Testing after the third manned period ended showed that the pumps operated satisfactorily except when used with inverter 1, and it was concluded that there was an unknown electronic problem in that inverter.

#### 8.4.2 Refrigeration Loops

During deactivation on Day 40, the solenoid-operated valve in the primary loop was operating normally to resume flow through the radiator after a period of bypassing the radiator because of low refrigerant temperature. There was an abrupt decrease of about 5 psi in the pressure rise across the pump, and there was a reduction in the temperature of the radiator surface during the succeeding orbits. Eventually, the material in the thermal capacitor completely melted, and the temperature of the refrigerant leaving the thermal capacitor rose above  $-14.5^{\circ}\text{F}$ . Temperatures in the frozen-food compartments then began to rise. When the temperature of the refrigerant supplied to the compartments reached  $1^{\circ}\text{F}$ , there was an automatic switchover to the secondary loop. The refrigerant in the secondary loop also showed a rapid rise in temperature, which indicated a similar anomaly.

Extensive ground testing was conducted to determine the cause of the malfunction and the effect of the malfunction on the capabilities of the system. The most probable cause was failure of the valve to close its bypass port completely, allowing only 20 percent of the total coolant flow through the radiator. If the port was 25 percent open, it would allow significant flow through the bypass. This would reduce the flow through the radiator, and mixing of flow from the radiator with the bypass flow would increase the temperature of the fluid entering the thermal capacitor. If contamination on the valve seat kept the valve from shutting off bypass flow completely, moving the valve from one position to the other could possibly clear it. The valve moves to the bypass position when the pump is turned off, and it moves to the radiator-flow position when the pump is turned on. By ground command, both loops were cycled on and off--the primary loop 105 times and the secondary loop 28 times--and then the first pump in the primary loop was left running. The valve was still stuck but some improvement was seen, and the coolant began to cool down. The performance was adequate for the rest of the mission. There was, however, almost no marginal capacity, and thereafter the refrigerant temperature varied slightly with changes in the temperature in the workshop. The mission was not affected.

## SECTION 9

### LABORATORY ATMOSPHERE

Skylab uses an atmosphere of oxygen and nitrogen, while previous manned spacecraft built by the United States used an atmosphere of pure oxygen. Since the command modules were designed for an internal pressure of only 5 psig, total pressure in the Saturn Workshop habitable volume is limited to 5 psia. The partial pressure of oxygen during manned periods is held at  $3.6 \pm 0.3$  psia, close to its normal sea-level value of 3.1 psia, and the balance of the atmosphere is nitrogen. Means are provided to purify the atmosphere, control the temperature and humidity, and circulate the gases throughout the laboratory. Additional information concerning this system is contained in references 8 and 10.

#### 9.1 GAS SUPPLY

The Saturn Workshop contains an atmosphere of dry nitrogen when it is launched. Ports open during ascent to reduce the internal pressure. After reaching orbit, it is repressurized in the correct proportions with oxygen and nitrogen stored at ambient temperature in external high-pressure tanks. The two gases are supplied automatically to maintain an atmosphere of the desired composition and pressure. Figure 9-1 is a schematic of the two-gas system.

Six tanks (fig. 4-1) contain the oxygen supply. They are connected in pairs to a manifold to allow gas to flow simultaneously from all of them. A check valve in the discharge line from each tank prevents backflow, so that there will be no loss from other tanks if one leaks. At launch, these tanks contained a total of 6113 pounds of oxygen at pressures varying from 2978 to 3013 psia and at temperatures from 67.7 to 71.6°F. The amount used during the mission was 3437 pounds. Since oxygen cannot be removed after the pressure in the tanks falls to 300 psia, 652 pounds of oxygen could not be used, and the available oxygen at the end of the mission was 2024 pounds. No leakage from the tanks or their associated plumbing was detected.

Nitrogen is stored in six spherical tanks (fig. 4-2). These tanks are connected in the same manner as the oxygen tanks, except that two of them are also connected to the recharging station for the astronaut maneuvering experiment. Flow from these two tanks can be added to the common flow if desired. The tanks contained 1630 pounds of nitrogen at launch, with pressures in individual tanks ranging from 2904 to 2990 psia and temperatures between 63.9 and 70.1°F. The amount of nitrogen used during the mission was 984 pounds, and the remaining usable nitrogen was estimated to be 469 pounds. There was no detectable leakage from these tanks or their connections.

Total gas usage during manned periods averaged about 11.5 lb/day, including metabolic consumption, leakage, and dumps. Metabolic oxygen consumption was estimated to be 5.52 lb/day, leakage about 2.68 lb/day, molecular sieve dumps about 2 to 2.5 lb/day, and miscellaneous dumps about 1 lb/day.

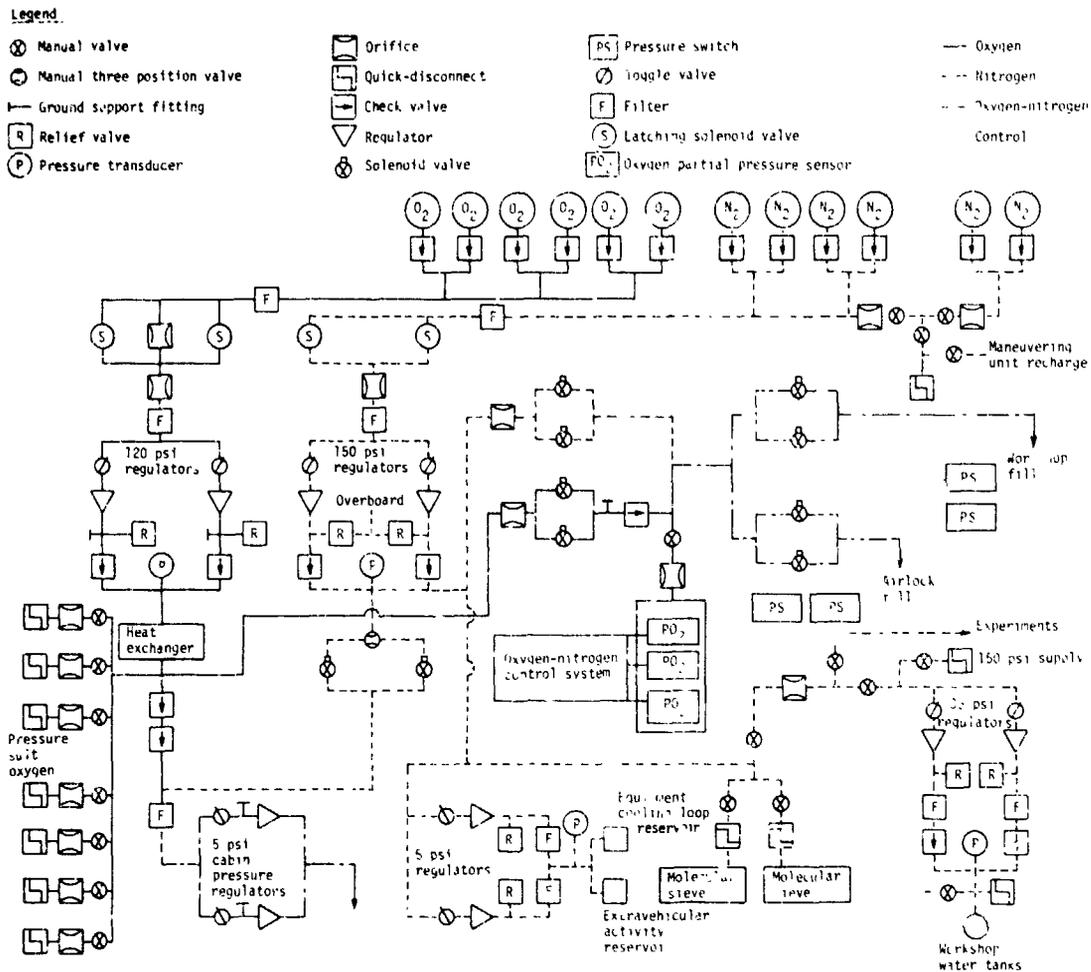


Figure 9-1.- Gas supply system.

Until shortly before launch, the workshop was purged and cooled by circulating gaseous nitrogen. The workshop and waste tank were then pressurized with dry nitrogen to 23.5 psia for structural stability during powered flight. Two parallel, pneumatically operated, normally closed workshop vent valves were opened 205 seconds after launch. Opening of the valves was scheduled so that pressure in the workshop would be at least 22 psia when maximum dynamic pressure occurred (fig. 9-2). The actual pressure in the workshop at that time was 22.78 psia. Venting continued until the pressure in the workshop reached 1.13 psia. The sphere containing high-pressure nitrogen for operating these valves and ejecting the launch protective covers was vented down after this, so that the valves could not reopen. Since the valves were not to be used again, the first crew capped them.

Continuous venting of the waste tank is required in orbit to maintain the pressure below the triple-point pressure of water. The vent ducts are diametrically opposed in order to cancel any thrust produced by the effluent. Venting starts in orbit approximately 10 minutes after launch, when pneumatically operated caps at the ends of two vent ducts are released. By 40 minutes after launch, the pressure had decreased to 0.02 psia. Except for a few short periods when unusually large quantities had been dumped into the waste tank, the pressure there

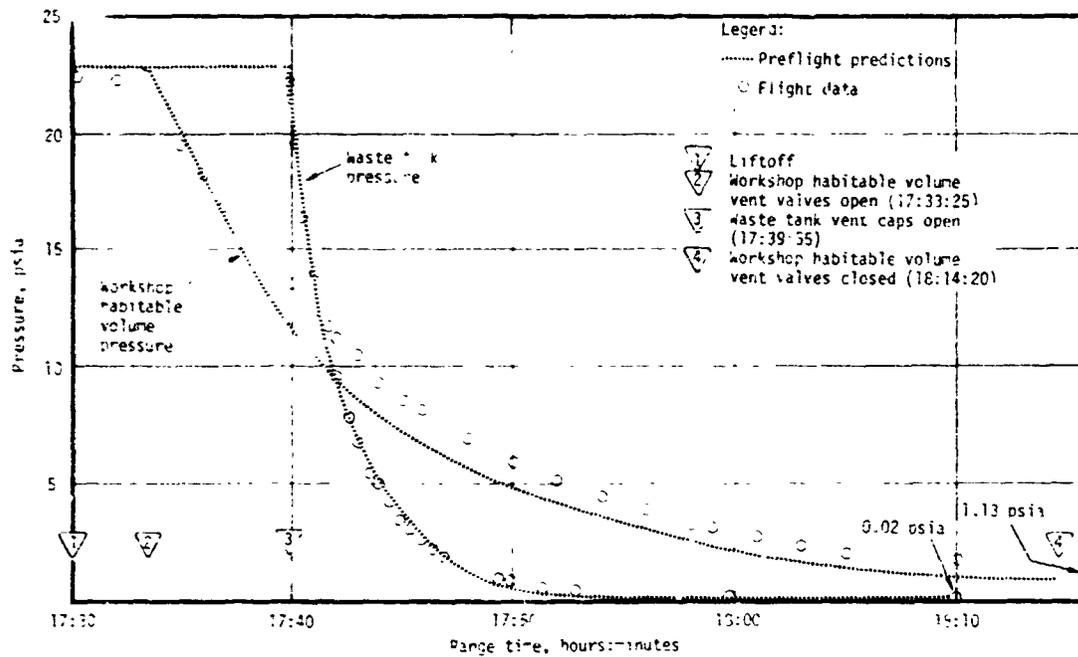


Figure 9-2.- Workshop depressurization during launch.

remained below the triple-point pressure throughout the mission. This low pressure is used to transfer fluids from the water system, washcloth squeezer, waste processor, and condensate system to the waste tank (fig. 9-3). It also serves to remove any coolant leakage in the refrigeration-pump enclosure. To eliminate the

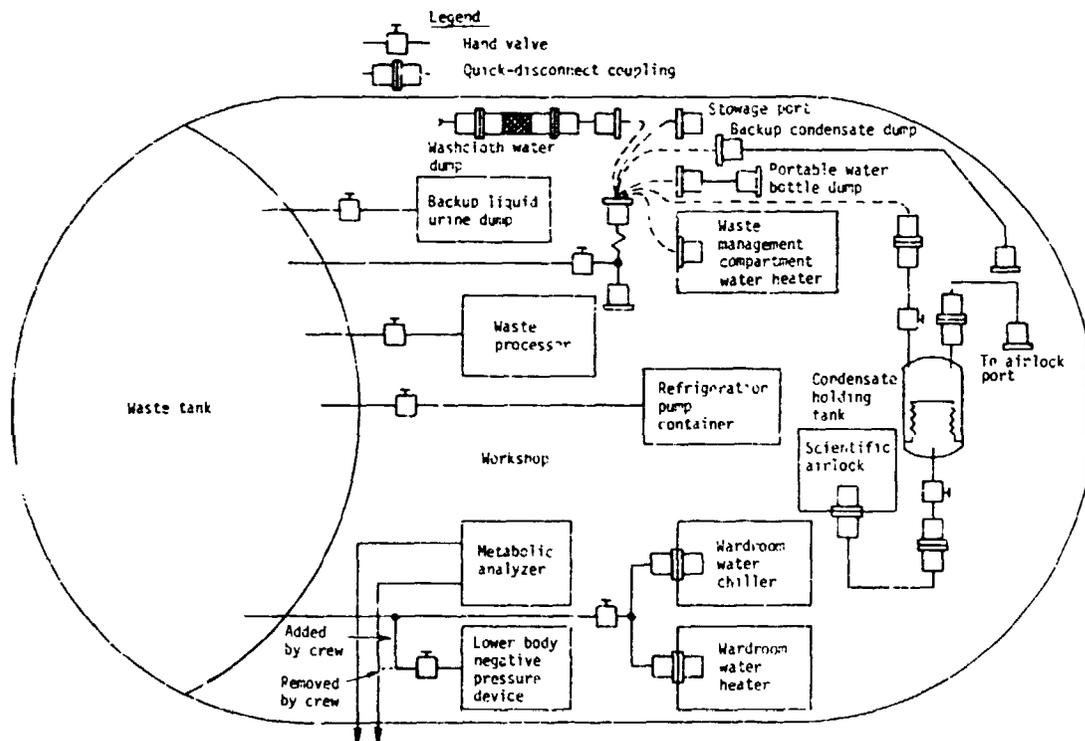


Figure 9-3.- Vacuum systems.

propulsive effects of the overboard vent, a line for evacuating the lower body negative pressure device was also connected into the waste tank by the crew.

Two motor-operated, 4-inch valves, connected in series to ensure that venting could be stopped, vent the docking adapter during launch. At launch, these valves were open, so that pressure inside the docking adapter and airlock would not exceed ambient pressure enough to cause structural damage. Both valves closed on command 288 seconds after launch. They were not used again, and the first crew capped them.

Four sets of solenoid-operated valves may be operated onboard or from the ground to pressurize the laboratory with oxygen, nitrogen, or a mixture of the two. Either the entire habitable volume is pressurized at the same time or the workshop and the remainder of the habitable volume are pressurized separately. After venting of the habitable volume was complete, the vent valves were closed, and the Saturn Workshop repressurized. The high temperature in the workshop introduced the possibility that toxic substances, particularly toluene diisocyanate from the polyurethane insulation, might be present. Any such contaminants were purged from the habitable volume by alternately pressurizing and venting. There are four solenoid-operated vent valves in the workshop to allow venting in preparation for the unmanned periods. These were used to vent the habitable volume during each cycle of venting and repressurization. Since the hatch leading to the workshop was closed, gas flowed from the rest of the habitable volume into the workshop through the check valves in the hatch. Five cycles were completed, ending with final pressurization before the first crew arrived. Figure 9-4 shows the vent repressurization history for the first 70 days of the mission. The time required for depressurization increased with each cycle because of debris collecting on the screens over the vent ports. After the final depressurization, two of the four valves failed to indicate closure on command. The two valves which did not appear to be closed are each in series with a valve which did close. The pressure stabilized, and the valves later operated normally during troubleshooting and when used to vent the laboratory after the crews left. The vent pressurization profile for the remainder of the mission was similar to the first manned and second unmanned periods, except that during the third unmanned period, the habitable volume was repressurized to provide cooling air for the supplementary rate gyro package. The pressurization system operated satisfactorily each time it was used.

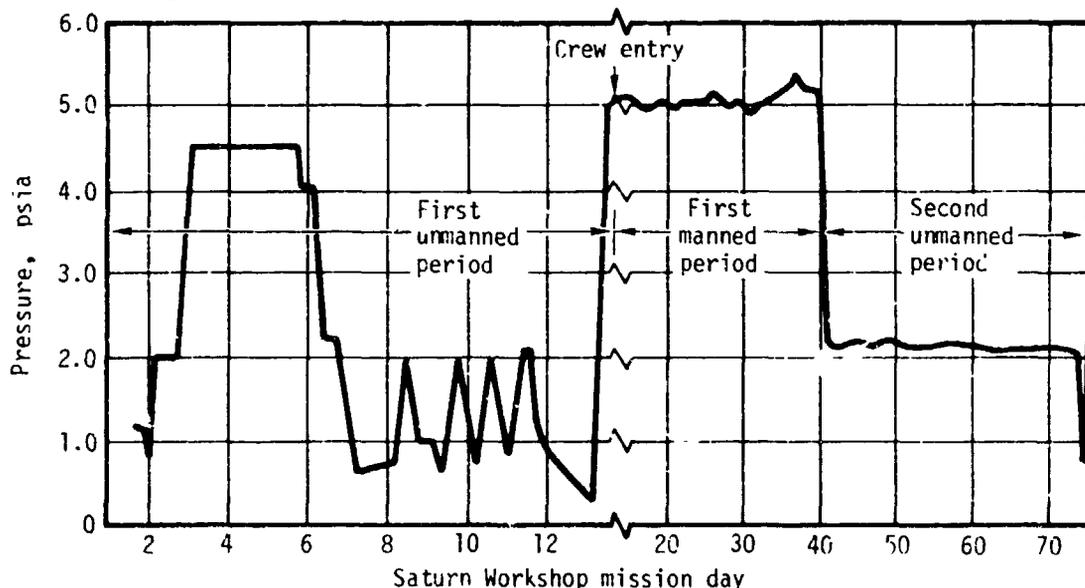


Figure 9-4.- Vent repressurization history.

After pressurization, the atmosphere is controlled automatically. Both gases are supplied at regulated pressure. Gas flows from the storage tanks to a regulator assembly consisting of parallel pressure regulators, a filter, relief valves, check valves, and shutoff valves. Each pressure regulator delivers a minimum flow of 22.8 lb/hr. Except for the nitrogen that flows directly from the storage tanks to the recharging station for the maneuvering units, the pressure regulators supply all oxygen and nitrogen.

One regulator assembly supplies oxygen at  $120 \pm 10$  psig. Oxygen flows from the regulator through a heat exchanger in which it is heated by the coolant in the laboratory cooling system. Oxygen leaves the heat exchanger at a temperature between 40 and 65°F and is supplied from this point for three uses: repressurizing the habitable volume before a crew arrives, automatic replenishment of the atmosphere during manned periods, and supplying space suits. Flow from these regulators was adequate, and the regulated pressure remained above its lower limit for the whole mission.

The other regulator assembly supplies nitrogen at  $150 \pm 10$  psig. Nitrogen at this pressure is used to replenish the atmosphere, repressurize the habitable volume, and operate control valves in the molecular sieve assemblies. It also goes to equipment for experiments. Some nitrogen at this pressure flows to other pressure regulators. One of these delivers nitrogen at 35 psia to pressurize water tanks, and the other supplies nitrogen at 5 psia for pressurizing water reservoirs of auxiliary cooling systems. Flow from this pressure regulator assembly was adequate for all uses, but decreasing outlet pressure caused concern until a corrective procedure was found. During the first manned period the outlet pressure gradually decreased from 160 to 140 psia. Then when the Saturn Workshop was deactivated and flow through the pressure regulators discontinued, the discharge pressure increased to 175 psia. The pressure at the start of the second manned period was 158 psia, but it decreased to 141 psia after about 27 days. Since stopping flow had restored pressure at the end of the first manned period, one pressure-regulating valve was shut off for 5 days. Then this valve was opened, and the other was closed. The discharge pressure immediately increased from 140 to 155.5 psia. Alternating use of the pressure-regulating valves continued through the second manned period. The discharge pressure still decreased, but more slowly, during the third manned period. One pressure-regulating valve was used continuously for the last 62 days of this period, and the discharge pressure held steady at 150 psia for the last 34 days. Attempts to reproduce this on the ground did not succeed, and the decreasing pressure has not been explained.

Normally during manned periods the atmosphere's pressure and composition are controlled automatically. Sensors continuously monitor both total pressure and partial pressure of oxygen in the atmosphere. Makeup gas is supplied through a  $5.0 \pm 0.2$  psia regulator to compensate for leakage and metabolic consumption of oxygen by crewmen. Whether oxygen or nitrogen is added to the atmosphere depends upon the partial pressure of oxygen detected by a sensor. A normally closed valve in the nitrogen supply line is opened by the controller to maintain the oxygen partial pressure within the  $3.6 \pm 0.3$  psia range. Check valves in the oxygen supply line close when the valve in the nitrogen line opens, since the nitrogen is at higher pressure than oxygen. Therefore, only nitrogen flows when the valve is open, and only oxygen flows when the valve is closed. Since power is required to open this valve, a loss of power or other failure affecting this valve would not shut off the oxygen.

When they were under automatic control, both the total pressure and the partial pressure of oxygen (fig. 9-5) stayed within their specified ranges.

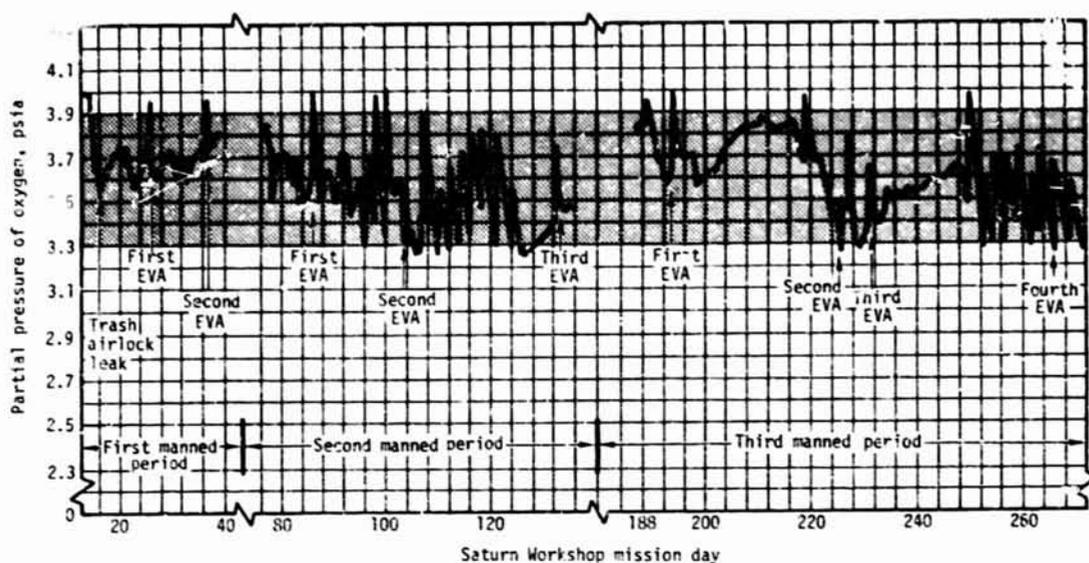


Figure 9-5.- Partial pressure of oxygen during manned periods.

There were, however, times during the mission when automatic control could not be used. During such operations as extravehicular activities and experiments with the astronaut maneuvering units, pressure and composition deviated slightly from their specified values.

## 9.2 ATMOSPHERE PURIFICATION

Gas flows continuously through two molecular sieve assemblies (fig. 9-6)

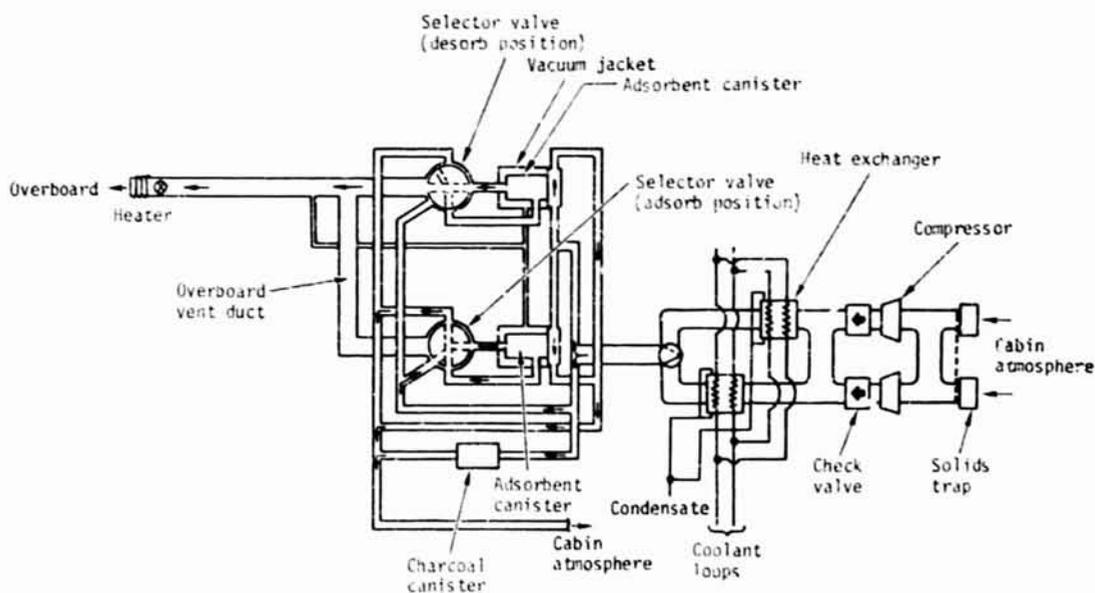


Figure 9-6.- Molecular sieve.

to remove water vapor, carbon dioxide, and odor-causing materials from Skylab's atmosphere. Each assembly (fig. 9-7) consists of two compressors, two condensing

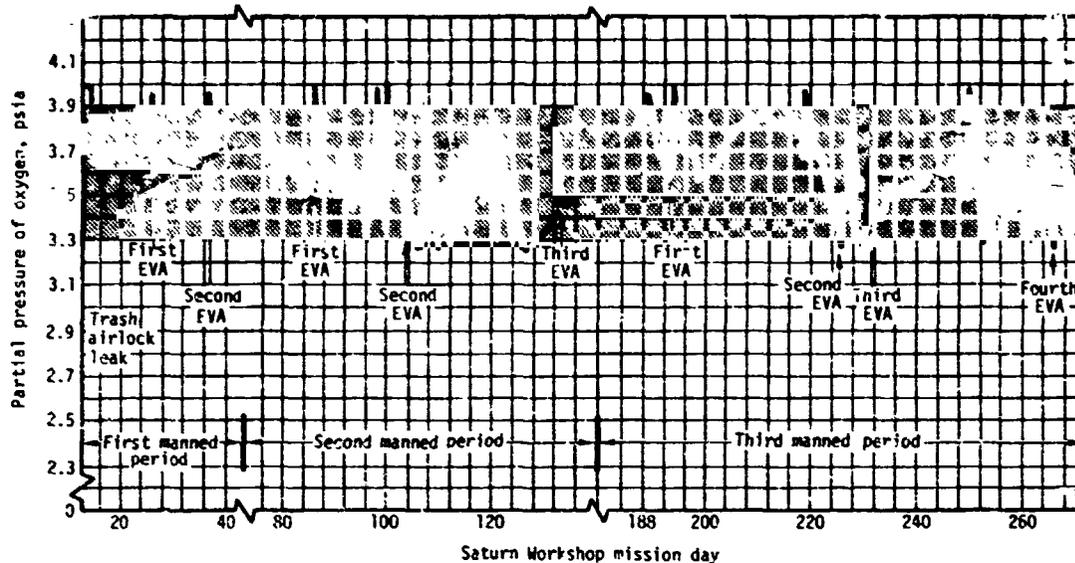


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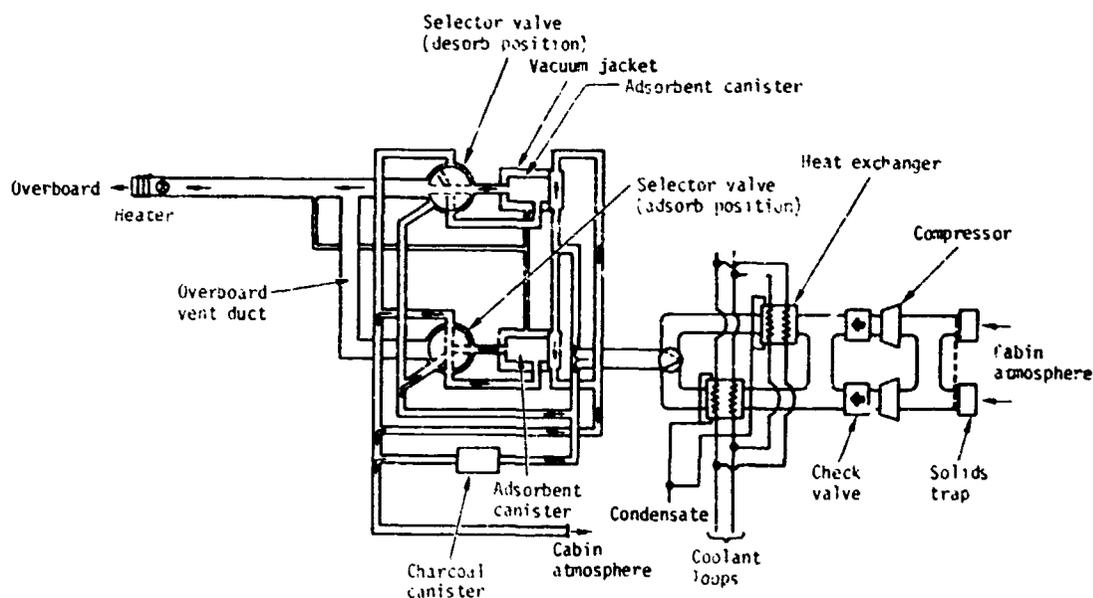


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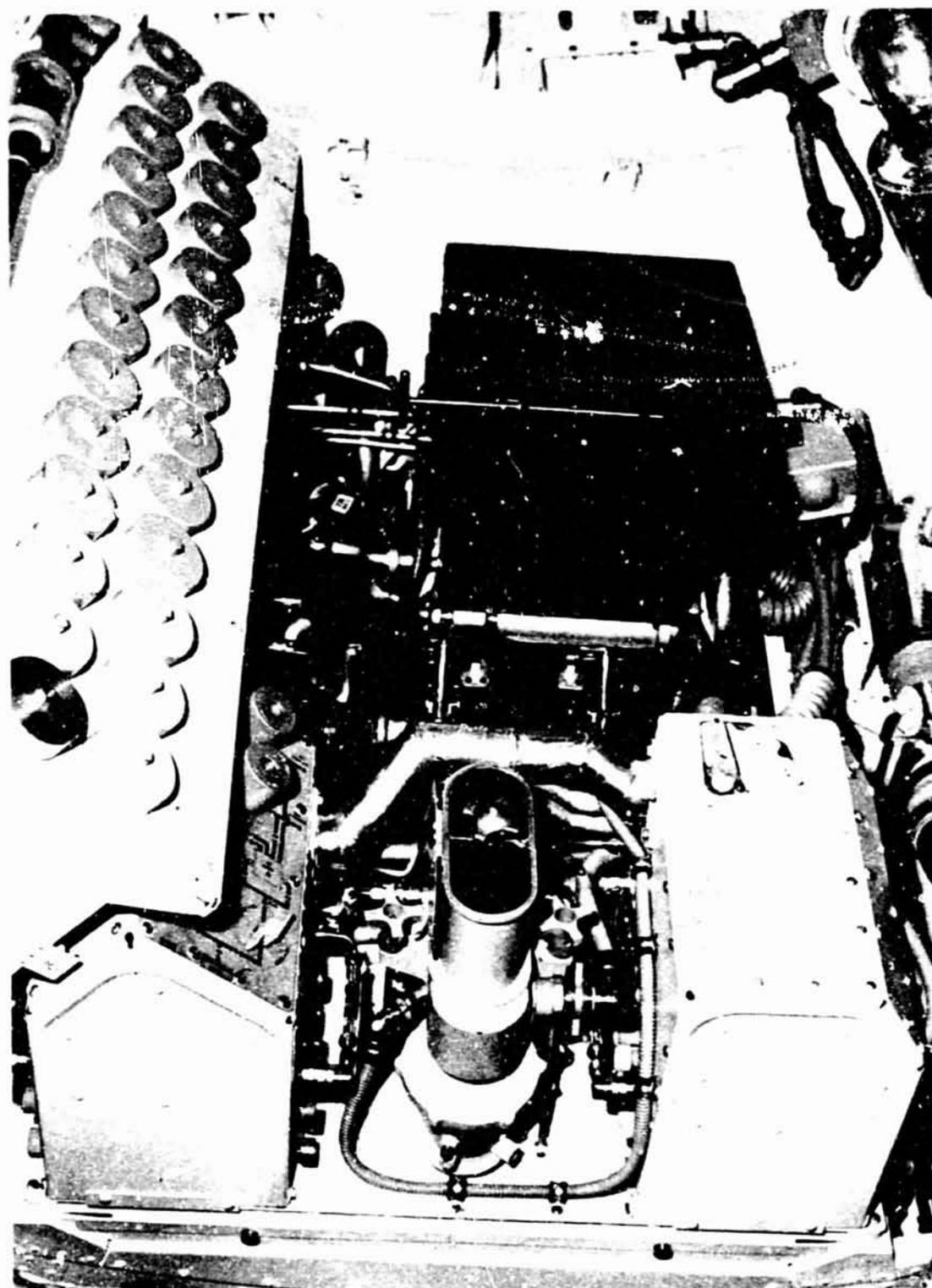


Figure 9-7.- Molecular sieve and stowed teleprinter paper rolls.

heat exchangers, two adsorbent canisters, and a charcoal canister. The heat exchangers dehumidify the gas, the adsorbent canisters further reduce humidity and remove carbon dioxide, and the charcoal removes odor-causing substances.

Normally, one compressor in each molecular sieve assembly is running, coolant is flowing through one condensing heat exchanger in each assembly, and no gas is flowing through either adsorbent canister of one assembly. Gas entering the molecular sieve assembly flows first through the condensing heat exchanger (fig. 9-8). In one assembly, gas leaving the heat exchanger divides into three streams. One stream passes through the charcoal canister, one flows through one of the adsorbent canisters, one flows through a bypass line, and then all three streams mix together. The flow through this assembly is about  $34 \text{ ft}^3/\text{min}$ , with about  $10 \text{ ft}^3/\text{min}$  going through the adsorbent canister. In the other assembly, the gas divides into only two streams; one passes through the charcoal canister and then mixes with the bypass flow. Because the adsorbent canister is closed off, flow through this assembly is only about  $29 \text{ ft}^3/\text{min}$ . These adsorbent canisters would be opened for gas flow and those in the other assembly closed off if the latter failed to remove carbon dioxide adequately or became unusable for any other reason. This was not necessary during the mission, however.

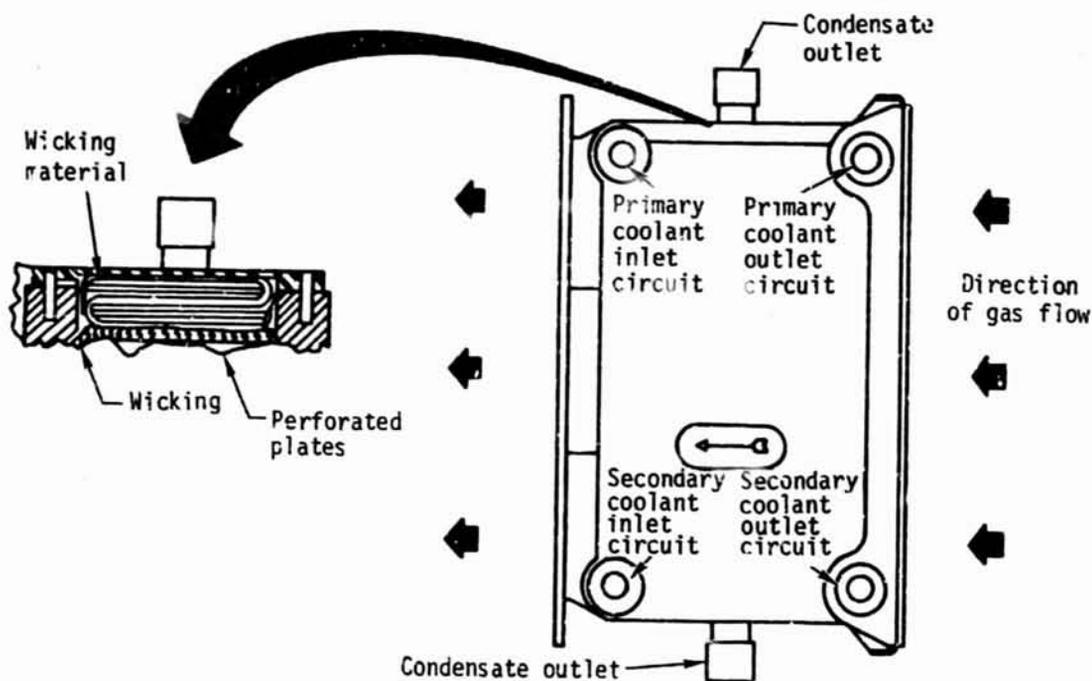


Figure 9-8.- Condensing heat exchangers.

The compressors, which are used only during manned periods, operated satisfactorily for the entire mission. Flowrates, calculated from measured pressure rise across the compressors, were very close to specified values. The inverter supplying power to one compressor failed on Day 187 (9.4.1), and the other compressor of that molecular sieve assembly was used for the rest of the mission.

The condensing heat exchangers sufficiently cool the gas passing through them to condense most of the water vapor. Plate-fin heat-transfer surfaces provide enough area to cool the gas to a temperature slightly above that of the liquid coolant entering the heat exchanger. The extended heat-transfer surface, with cross-counter flow on the liquid side, permits single-pass flow on the gas side. The temperature of the coolant entering the heat exchanger is controlled to  $47 \pm 2^\circ\text{F}$ .

Weightlessness requires a special technique for collecting water condensed in the heat exchangers. Fiberglass wicking material covering the heat-transfer

surfaces provides an absorbent layer which collects condensate, and a path through which condensate flows by capillary action to separators at each end of the heat exchanger. The separator is a stainless steel grid sandwiched between filters made of sintered glass. It is wrapped in a sheet of open-cell polyurethane foam that is in contact with the fiberglass wicking material to provide a continuous capillary flow path to the surfaces of the filters. The space inside the separators is at a lower pressure than the Saturn Workshop's atmosphere, and this pressure difference drives the condensate through the filters. Unless the filters are thoroughly wet, gas will also pass through them. Although water condensing on the heat exchanger would wet the separators, the preferred procedure was for the crew to wet the separators while activating the molecular sieve assemblies. All three crews followed this procedure, but commented that it was hard to tell when the plate became wetted. The original set of plates was used for the entire mission.

The only unusual incident occurred on Day 25. Control valves in the coolant loops stuck (8.4.1) and reduced the temperature of coolant entering the heat exchangers, apparently causing the condensate to freeze. Instrumentation indicated no flow. The crewmen could not directly observe any ice on the heat exchangers, but they reported that they could feel no flow of gas into the compressors, although they could hear the compressors. The lack of flow indicated the atmosphere flow path was blocked. Normal flow resumed after the coolant's temperature increased above the freezing point of water.

Condensate is stored temporarily before being disposed of. It flows from the heat exchanger to one of two storage tanks (fig. 9-9). Condensate can flow into either one or both of the tanks. In practice, the workshop tank was the

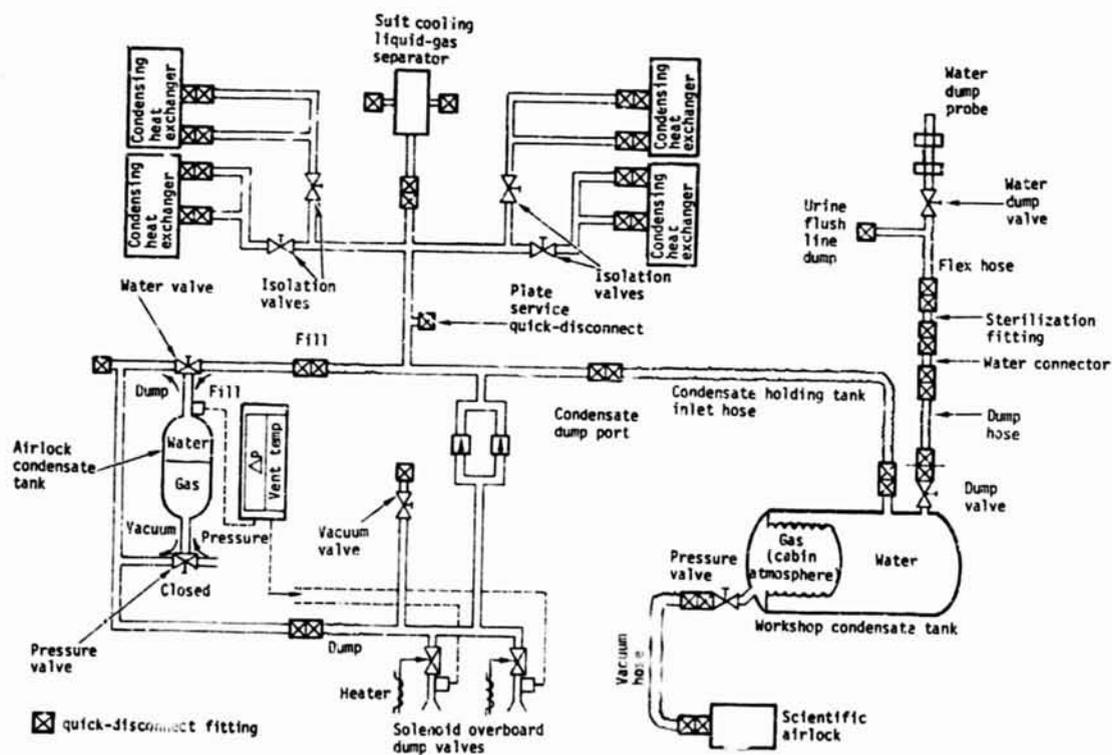


Figure 9-9.- Condensate system.

primary storage vessel, as it had about 40 times the volume of the airlock tank, shown in figure 9-10. Both condensate tanks operate on the same principle. A

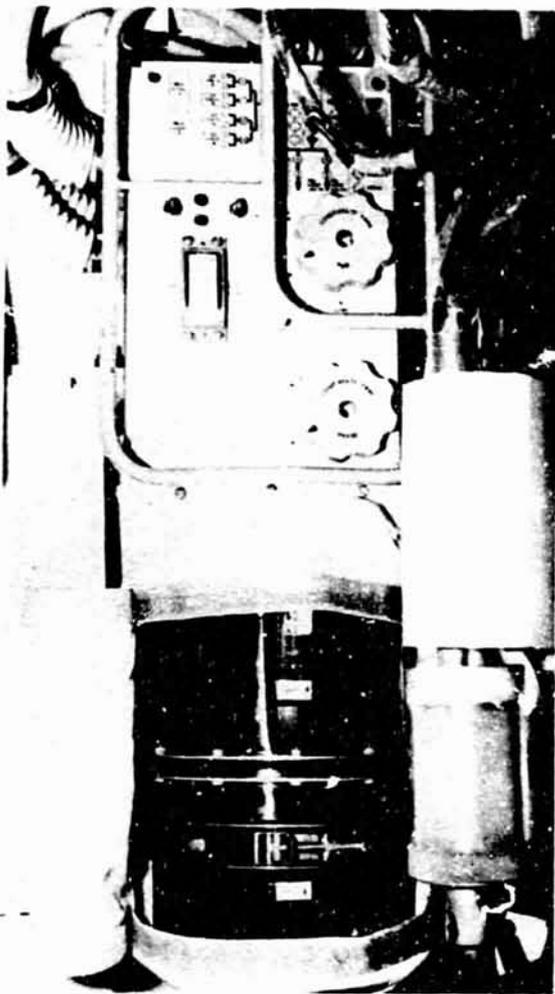


Figure 9-10.- Airlock condensate storage tank.

flexible divider (a diaphragm in the smaller tank and a bellows in the larger) partitions the space inside the tank into two regions (fig. 9-11). Opening one region to vacuum while the other is sealed causes the divider to deflect so that the sealed region's volume increases. Pressure in this region decreases. The line connecting this region to the separators is opened so that condensate can flow into the tank, and the other region of the tank is closed off. As condensate flows into the tank the pressure increases. Emptying the tank is necessary when the difference between the pressure in the habitable volume and that in the tank decreases enough to make separation and collection of condensate ineffective. The part of the tank containing the condensate is opened to a lower pressure (the overboard dump line or the waste tank), and pressure is admitted to the other side of the divider. As the divider deflects, it expels the condensate. Although collection and disposal of condensate were carried out successfully throughout the mission, gas leaks prevented use of the full capacity of the condensate tanks at times (9.4.2).

take place as water discharges into the waste tank, cooling the water. The heater keeps water from freezing in the line and blocking it. There was one incident of ice forming and preventing condensate from being transferred to the waste tank. Several attempts to clear the line were only partially successful, so the crew replaced the discharge probe. The trouble did not recur, although there was apparently nothing wrong with the heater that was removed.

After leaving the condensing heat exchanger, part of the gas flowing through one of the two

Condensate is transferred from these tanks to the waste tank through a line ending in a discharge probe equipped with an electric heater. Low pressure in the waste tank causes evaporation to

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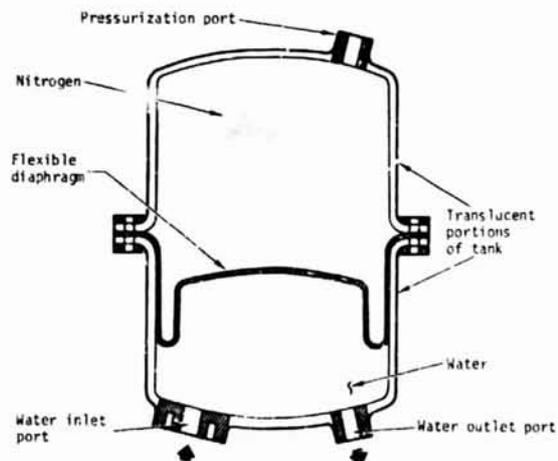


Figure 9-11.- Airlock condensate storage tank.

molecular sieve assemblies passes through an adsorbent canister. Two adsorbent canisters are used alternately; while gas is flowing through one, the other is vented to space to remove adsorbed gases. Each canister passes from one operating mode to the other every 15 minutes. A three-way valve connected to each canister directs the flow. One position of the valve allows gas to flow through the adsorbent canister, a second position stops gas flow and vents the canister to space, and the third position shuts off all flow into and out of the canister. High-pressure nitrogen from the regulated supply actuates the valve, as commanded by a cycle timer. Each canister (fig. 9-12) contains two separate adsorbent beds. The synthetic zeolite for removing carbon dioxide also has an affinity for other polar compounds, particularly water. Although the gas leaving the condensing heat exchanger has a low dewpoint, it still contains enough water vapor to reduce greatly the capability of the adsorbent to remove carbon dioxide. Therefore the first section of the canister contains a type of synthetic zeolite which preferentially adsorbs water. Drying the gas ensures that carbon dioxide is removed efficiently in the second section. Tests conducted during development showed that the adsorbents were also effective in removing a variety of organic and inorganic compounds from the gas stream, including the coolant used in the laboratory. The coolant and some other compounds in this group are potential contaminants of the Saturn Workshop's atmosphere, so capability to remove them was an advantage.

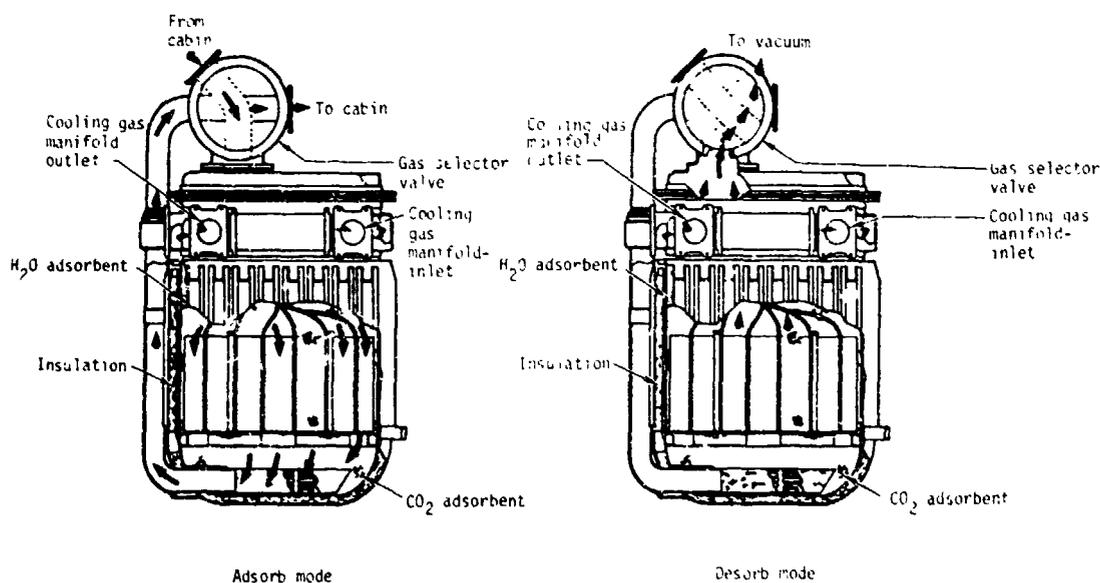


Figure 9-12.- Adsorbent canister.

Removing water in the adsorbent canister helps to control humidity in the habitable volume. Dewpoints were generally maintained within the specified range of 46 to 60°F. Initially, the laboratory contained almost no water vapor, since it had been purged with dry nitrogen when the Saturn Workshop was launched. High temperatures in the workshop and purging with nitrogen before the first crew arrived could have dried out hygroscopic materials so completely that it would have taken excessive time for the dewpoint to rise to the minimum value of 46°F. However, the dewpoint reached 46°F after only 7 hours. The workshop was still hot, and a high rate of water evaporation by the crew as they worked there helped to increase the humidity. Later, dewpoints below 46°F occurred several times. During extravehicular activities, when only one crewman was in the laboratory, the dewpoint decreased, but returned to normal shortly after the activity ended.

The dewpoint also fell below 46°F as a result of the valve problem in the laboratory cooling system, resulting in crew comments that the humidity was too low. There were several times while a crewman was using the shower that the dewpoint rose briefly. It reached 57°F during use of the shower on Day 251, high enough for condensation to take place in the cabin heat exchangers.

Alternating between adsorption and desorption maintains the adsorbents' effectiveness, but desorption at ambient temperature does not ensure complete removal of water and carbon dioxide. Complete regeneration of the adsorbents requires bake-out of the canister. This is accomplished by venting one canister at a time to space, while an electric heater maintains its temperature at 400°F for approximately 5 hours. Experience showed that regenerating the adsorbents was not needed as frequently as had been expected. It had been planned to execute this procedure at the beginning of each manned period and to repeat it after 28 days during the second and third manned periods. Each crew, in the course of activating the Saturn Workshop, carried out the procedure for regenerating adsorbents. The second crew repeated the procedure after 24 days of operation, following an increase in concentration of carbon dioxide in the habitable volume. Subsequently, the concentration was lower. It stayed low throughout the third manned period, and regenerating the adsorbents was not necessary. The concentration of carbon dioxide in the Saturn Workshop remained at a satisfactorily low level during the mission. Preflight analyses based on metabolic rates and adsorption efficiencies gave an estimated value of 5 mm-Hg for the partial pressure of carbon dioxide during the manned periods. Actual values during the first manned period were very close to this. The partial pressure was somewhat higher during the second manned period, with a daily average of about 5.5 mm-Hg. It returned to the lower values of the first manned period during the third manned period.

To remove odoriferous compounds such as butyric acid, hydrogen sulfide, and indole, part of the gas flowing through each molecular sieve assembly passes through a canister containing activated coconut charcoal. The charcoal cannot be regenerated, so spare canisters were provided. The crews replaced both charcoal canisters at the same time. The ventilation unit in the waste management compartment also contains a charcoal canister. The first crew replaced the canisters on Day 39. The second crew changed canisters on Day 114, when the canisters had been in use for about 39 days, and again on Day 134. The third crew changed the canisters, which had been in use for about 45 days, on Day 231. Analysis of charcoal samples from the returned canisters disclosed a variety of adsorbed compounds. Methanol, ethanol, isopropanol, and acetone were the major detectable compounds other than water. Canisters removed during the second manned period showed traces of coolant. Comments made by the crews provide the only means of assessing the suppression of odors in the Saturn Workshop. These comments were quite favorable: "No problems...; when we entered [the laboratory], we were quite pleasantly surprised....Waste management compartment odor removal was outstanding....Odors just did not persist...."

### 9.3 VENTILATING AND CONDITIONING

The atmosphere in the laboratory circulates continuously to ensure uniform temperatures and to prevent local concentrations of carbon dioxide or water vapor. The circulation system includes provisions for heating or cooling the gas to maintain comfortable temperatures (fig. 9-13). Flow from the molecular sieve systems can be directed to either the workshop or the docking adapter or to both. Cool gas from four workshop heat exchangers is mixed with this flow and additional

flow from the structural transition section and routed to a mixing chamber in the workshop forward dome.

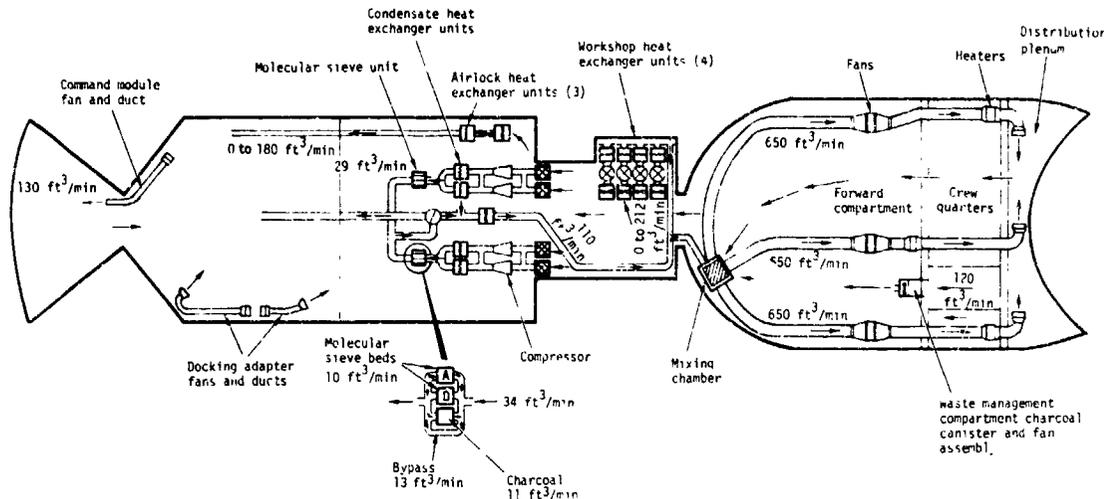


Figure 9-13.- Skylab ventilation system.

Three ducts carry this gas and additional gas from the forward compartment to a plenum beneath the floor of the crew quarters. Fixed ducts carry gas cooled by heat exchangers in the airlock to the docking adapter. A flexible duct and fan circulate gas to the command module. The duct that carries gas to the workshop mixing chamber passes through the hatchway in the workshop's forward dome. Before the Saturn Workshop was launched, the hatch was closed and the duct stowed. The first crew installed this duct after opening the hatch leading into the workshop. The duct had to be removed and replaced to close the hatch for each extravehicular activity. The duct leading to the command module passes through the docking port, and each crew had to put it in place while activating the Saturn Workshop and remove it before undocking. Gas enters the workshop through adjustable diffusers in the floor of the crew quarters. None of the crews changed the settings of the diffusers from the wide-open position they had at launch. Outlets in the sleep compartments are also adjustable, and the crewmen set them for comfort. Air distribution and velocity at crew stations in the docking adapter could also be controlled by adjustable diffusers and cabin fans.

Circulation is provided by 27 identical fans. There is a cluster of four fans in each of the three ducts leading to the plenum in the workshop. Two fans control local velocities in the docking adapter, and one fan delivers gas from the docking adapter to the command module while a crew is aboard. Seven fans operate in conjunction with cabin heat exchangers to supply cooled gas; these fans, four supplying the workshop and three supplying the docking adapter, operate as required. Another fan draws gas from the waste management compartment and discharges it to the workshop through a charcoal filter to control odor. A fan in the discharge duct from the molecular sieve assemblies directs gas to the mixing chamber. The remaining three fans are part of portable fan assemblies that also include screens and noise-suppressing mufflers. These fans were designed for an earlier program which require only a short operating lifetime. All three crews used a portable fan some of the time to increase gas flow to the heat exchangers that supply cool gas to the workshop. The first crew used a portable fan to provide more circulation in the workshop. A portable fan was sometimes used to cool a crewman operating the ergometer, and one was used to

cool the rate gyros in the docking adapter. Nine spare fans were carried, but none of the fans failed during the mission. The fans operated as much as 1500 hours longer than their design life of 3360 hours because of some unplanned use and the extended mission period.

Four heat exchangers (fig. 9-14) can supply cooled gas to the mixing chamber. If the temperature in the diffuser outlets exceeds the set point by  $1^{\circ}\text{F}$ , a fan that directs gas through one heat exchanger is turned on. With each additional increase in temperature of  $1^{\circ}\text{F}$ , another fan turns on, until all four fans are running. All operating fans are turned off if the temperature in the mixing chamber falls to  $2^{\circ}\text{F}$  below the set point. Automatic control is also provided for eight of the heater elements in the workshop ducts. The remaining four heater elements have manual control. Automatic control of the heater elements is similar to the heat exchanger fans. If the temperature decreases  $1^{\circ}\text{F}$  below the set point, two heater elements come on. If it drops to  $2^{\circ}\text{F}$  less, four heater elements turn on, and so on. When the temperature exceeds the set point by  $2^{\circ}\text{F}$ , all

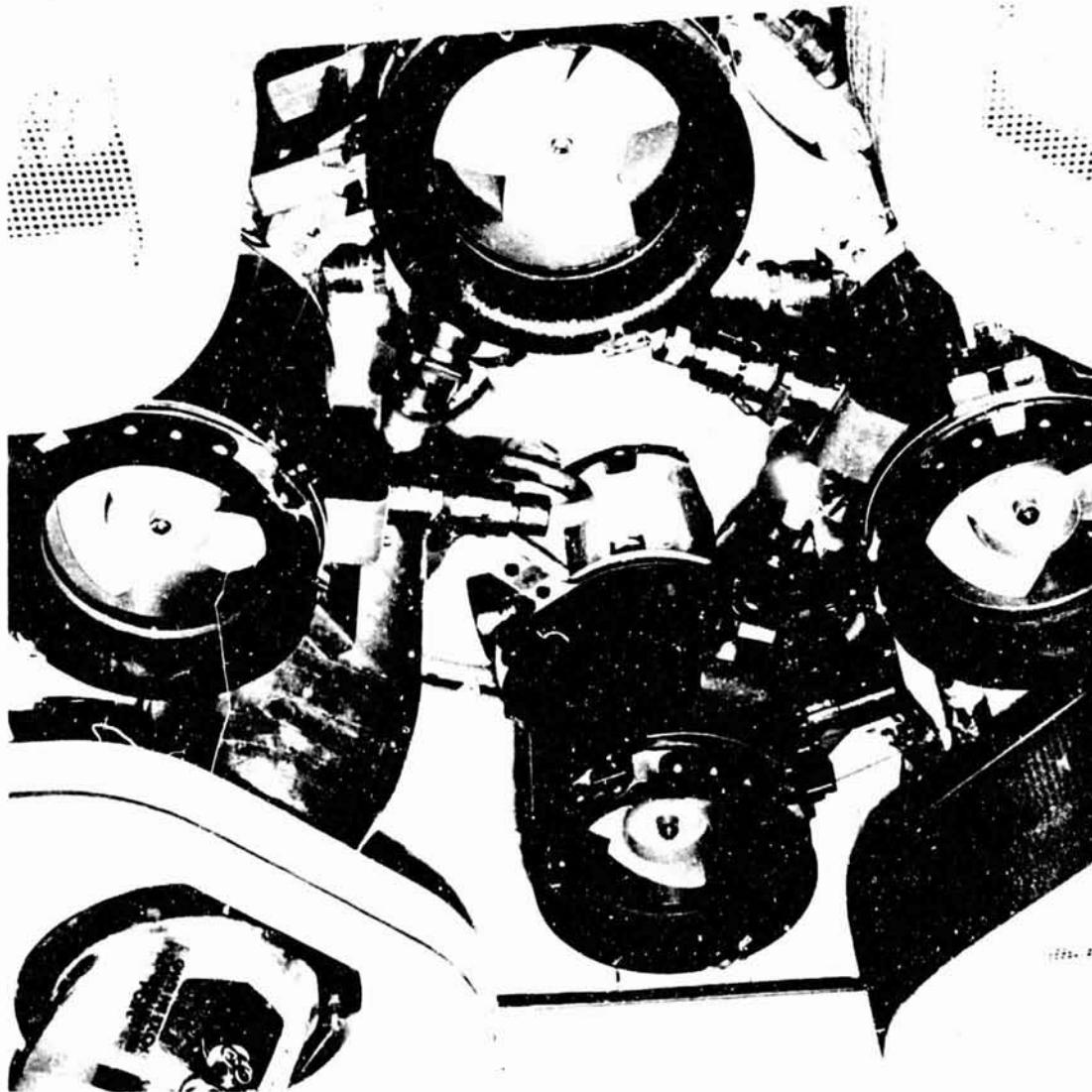


Figure 9-14.- Cooling heat exchangers.

heaters turn off. The heaters were never used during the mission, since the loss of the meteoroid shield increased the rate of solar heating of the workshop.

During the initial unmanned period, when high temperatures in the workshop were of extreme concern, cooled gas could not be supplied to the workshop because the hatch in the workshop's forward dome was closed and the cooling system required crew activation. Only when the first crew opened the hatch leading into the workshop and installed the duct leading to the mixing chamber was there any cooling available in the workshop. The heat exchangers were not turned on as soon as the crew entered the workshop, however, because of the limited power available at that time. First, the crewmen deployed the parasol thermal shield to reduce the rate at which heat entered the workshop. Then, Skylab was maneuvered to the solar-inertial attitude. With power then available, the fans for all four heat exchangers were turned on. These events took place on Day 14, and temperature in the workshop immediately decreased (fig. 8-4). All four heat-exchanger fans continued to run for the rest of the first manned period, except when they were turned off during extravehicular activity. Operation of the fans during unmanned periods, when pressure in the laboratory was low, was not planned.

During the second manned period, the temperature control unit maintained the thermal control system in the full cooling mode (four heat exchanger fans) until Day 118. At this time all heat exchanger fans were turned off when the temperature was 69.2°F, which was 1.4°F below the set point. The control system later turned on the heat exchanger fans one by one as the temperature increased, according to the control system logic. An analysis of the flight data indicated that the unit performed its functions correctly within 0.6°F of the design requirements.

During the third manned period, the control unit maintained the full cooling mode until Day 199. At that time, the temperature was 71°F. The crew changed the select temperature to 73.3°F and all heat exchanger fans were turned off. On Day 207, when the temperature had reached 75°F, the crew changed the select temperature to 71.1°F and all heat exchangers were turned back on. All heat exchanger fans continued to run the rest of the mission except when turned off for the extravehicular activity periods. The automatic control unit was deactivated on Day 248 to aid in reducing the internal heat generation in the workshop.

After the workshop, the docking adapter is the scene of the greatest amount of crew activity. Three fans in the structural transition section supply cooled gas through three heat exchangers. Fixed ducts carry the cooled gas to the docking adapter, and gas can also flow into it from the molecular sieve assemblies. There is no direct control of temperature in the airlock and structural transition section, but return flow from the workshop and docking adapter prevents temperatures in these regions from differing greatly from those elsewhere.

The crew's comments on ventilation were favorable: "The ventilation and atmospheric cooling were good....Ventilation was great. Fans don't make much noise." There was some reduction in flowrate that was attributed to dust in the screens. This was improved by more frequent vacuuming (10.1.7). When the dew-point reached 57°F on Day 250, condensation in the heat exchangers decreased gas flowrates. Flow returned to normal on Day 252 when the condensation was removed with the vacuum cleaner.

## 9.4 ANOMALIES

### 9.4.1 Molecular Sieve Inverter

A compressor in one molecular sieve assembly failed to start during activation at the beginning of the third manned period on Day 187. The trouble was traced to the inverter supplying power to the compressor. The other compressor in the same assembly started, and it was used for the third manned period. No reason for the failure was ascertained. A cable was carried by the third crew which would have allowed operation of the compressor from an inverter in the other assembly, but it was not needed.

### 9.4.2 Water Condensate System

During the first manned period, the pressure in the condensate system, as measured in the smaller tank, was 3.2 to 4.5 psi less than that in the laboratory, but when the larger tank was disconnected, the pressure difference decreased more rapidly than expected. Since the leak caused the pressure difference to decrease rapidly when the larger tank was disconnected, the leak appeared to be somewhere on the gas side of the smaller tank. A spare was available, and this tank could have been replaced. Disconnecting the other tank was, however, required only infrequently and for short times, so making the replacement did not seem warranted.

An additional problem occurred during the second manned period. The pressure difference was initially 4.2 psi, and this held until waste water was transferred from the command module. The pressure difference then started to decrease. The crew tried unsuccessfully to locate the leak and stop it. The rapid rise in pressure made it necessary to dump condensate nearly every day. Finally, the leakage stopped when a quick-disconnect fitting was uncoupled from the smaller tank on Day 112; after this, no leakage was observed for the rest of this period.

There was apparently no leakage during the third unmanned period, during which time a pressure difference of 2.9 psi was maintained. Performance was satisfactory until Day 266, during the third manned period, when a quick-disconnect fitting was disconnected. The pressure difference decreased to zero in about 15 minutes. Sealant applied to the fitting failed to reduce the rate of leakage. The crew then put a cap over the fitting, and no more leakage was observed.

## SECTION 10

### CREW SYSTEMS

Crew systems, as used here, includes the equipment provided for living and working in the Saturn Workshop and the man-machine interface with other systems. The design of some systems, such as those for extravehicular activity support, drew largely on previous space flight experience. Other systems, particularly those for the body functions of eating, sleeping, and human waste disposal, were based on several new concepts. Some of the more common functions such as stowage required adaptation of previous concepts to a new and larger environment.

The spaciousness of the Saturn Workshop permitted development and testing of new mobility concepts and work orientation arrangements. Planned inflight maintenance was introduced because of the mission duration. However, repairs to equipment far beyond those envisioned prior to the mission were accomplished.

The equipment and subsystems described and evaluated in this section include the mechanical and electrical components that are an integral part of the subsystems. Interfaces with other systems such as experiments and environmental control are evaluated only with respect to the human factors involved. Evaluation of crew-related functions and equipment developed by or under the cognizance of the Johnson Space Center are not reported here, although they are mentioned when necessary because of an interface with other activities. Additional information on these can be found in references 15 through 17. More detailed discussion of crew systems is contained in references 8, 10, and 11.

#### 10.1 HABITABILITY PROVISIONS

The size of the Saturn Workshop made possible by the payload capability of the Saturn V enabled the crew to be provided with habitability systems and equipment that are more sophisticated than any previously provided in a spacecraft. The crew's quarters are compartmentalized for the various functions of eating, sleeping, body waste elimination, and experiment operation.

Although "up" and "down" are arbitrary in space, the workshop was designed with a "visual gravity vector." One surface is designated the floor, and all operations and labeling are planned around this reference surface. Some deviations from this concept were required as the design progressed; for example, the sleep restraints are suspended vertical to the floor, and the fecal collector requires that the crewman sit on the wall. The gravity vector orientation was not followed in the docking adapter and airlock because of space and layout considerations. Some of the equipment in these is radially oriented and some is longitudinally oriented.

##### 10.1.1 Crew Stations

The term "crew station" is used to describe those areas where a crewman spends considerable time performing tasks. The work space, layout, arm-reach

envelopes, habitability, and compatibility of the stations inside the Saturn Workshop (fig. 10-1) are considered. The external work stations used during extravehicular activities are discussed in 10.5.

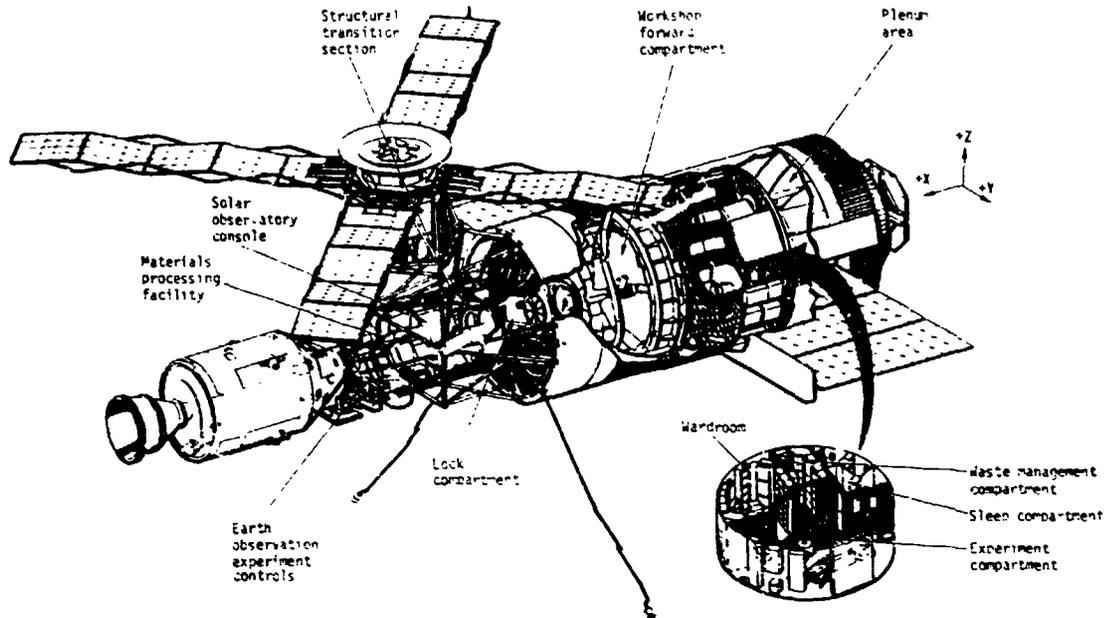


Figure 10-1.- Crew station locations.

The equipment in the workshop is arranged on compartment walls, floors, and ceilings, as well as about the cylindrical walls. This is possible because of the compartment divisions on the crew quarters level and two open grid floors which divide the cylindrical volume. This configuration provides more of a one-gravity orientation with floor to ceiling effects. The equipment in the docking adapter and airlock is arranged about the surfaces of the cylindrical walls. A somewhat dissociated arrangement of equipment resulted from the growth in the number of experiments and continual additions of stowage items during development.

The performance of the Skylab crews proved that man can function effectively in a cylindrical module such as the docking adapter. The crewmen took longer, however, to adapt to working in this layout than in the floor to ceiling layout of the workshop. Each of the crews expressed an orientation problem when translating into the docking adapter until they found a familiar piece of experiment hardware. It also took the crewmen longer to locate a particular stowage container in the docking adapter than in the workshop. This suggests that it would be more efficient to lay out experiment and stowage hardware in a gravity orientation even in small cylindrical volumes. Stowage containers could be grouped along one axis or radially in a particular location.

Earth Observation Control and Display.- Located in the forward end of the docking adapter, this station consists of a control and display panel, the experiment camera array and stowage container, a speaker intercom assembly, and a foot restraint. The foot restraint serves both the control and display panel and the materials processing facility station. The crew expressed satisfaction with this station.

Earth Observation Viewfinder Tracking.- This station is in the forward end of the docking adapter and includes the viewfinder tracking system, its associated control and display panel, and a clipboard on an experiment cable cover. No foot restraint is provided, but there are handholds on the panel for crew positioning and operation. The intercom at the materials processing facility station is shared with the viewfinder tracking station. The crewman may also use the Earth observation control and display panel and intercom from this station. The lack of a foot restraint at the viewfinder tracking system was the most significant drawback of the station. It was found highly desirable to have a foot restraint for long duration work or at stations which required the operation of controls and handling of charts and checklists. The only other problem was that the clipboard mounting provisions unsnapped several times during use.

Materials Processing.- This station is located toward the forward end of the docking adapter and consists of the experiment facility, an intercom, a foot restraint, and controls for venting the experiment chamber. The foot restraint is the same unit provided for the Earth observation control and display panel, but repositioned for this experiment. The wall mounting of the experiment and the placement of the foot restraint provide the crewman with access to all of the experiment equipment, the intercom, and the two experiment chamber vent valve handles. The resultant position for the crewman is a compromise between a standup attitude and a position wherein he leans slightly forward to operate the facility. Operation of the facility was as planned, and no major problems were reported. Unplanned stowage of a pressure suit near the crewman's head appeared to cause a minor infringement of the working space.

Solar Observatory Console.- This is at the aft end of the docking adapter and consists of a control and display console, a foot restraint, a chair, and an intercom (fig. 10-2). The console was originally designed for use by seated crewmen in the Apollo lunar module, and the basic size and shape of the console did not change when incorporated into Skylab. The chair can be mounted to the foot restraint if desired.

The crew comments were generally favorable, except that the crewman operating the console interfered with other crewmen translating through the laboratory or working in the area. This was an annoyance, since the console was occupied a good part of the time. Crewmen could not read their checklists by the console integral panel lighting alone. When the docking adapter floodlights were turned on, the edge lighting effect disappeared but the panel markings could still be easily read. Some crewmen preferred using the chair, and some preferred the foot restraint. Those who used the foot restraint alone found everything within easy reach. Use of the chair restricted freedom of motion and reach.

Structural Transition Section.- This station, in the forward part of the airlock, consists of the control and display panels, hardware stowage containers, four viewing windows, handrails, and handrail lights. It is arranged in four equipment groups to allow space for access to the windows and for maintenance of the equipment. The space is large enough for a crewman with cameras, sextants, or other optical viewing devices, yet small enough that sufficient body restraint can be obtained for performing two-handed tasks by bracing between adjacent equipment surfaces. Handrails and handrail lights are installed at strategic locations as an aid during translation and for protection of equipment. Ancillary equipment, located in the adjacent airlock forward compartment,



Figure 10-2.- Solar observatory console work station.

consists of the tape recorder module, the caution and warning system klaxon, and stowage containers for spares. There are no lights or control panels in this compartment. The klaxon is located behind the opened airlock forward hatch so that the hatch acts as an audio baffle, providing aural protection for a crewman should he be nearby when it is energized.

The radial arrangement, orientation, and grouping of the control panels were convenient and worked well. The windows proved to be of greater value than had been expected, and were used extensively for extravehicular activity coordination, attitude correlation, external structure inspection, and general viewing. They were also invaluable for unscheduled events such as deployment of the thermal shield and workshop solar array wing and the periodic monitoring of the shield's condition and orientation. The design and arrangement of the handrails were good although there were insufficient restraints available to perform the unscheduled coolant loop servicing.

Lock Compartment.- This station in the airlock tunnel (fig. 10-3) consists of the extravehicular activity hatch, two internal hatches, two extravehicular activity control panels, a control panel and valves, and two film tree receptacles. The control panels are radially oriented in the compartment. The equipment required for extravehicular activities is located near the hatch.

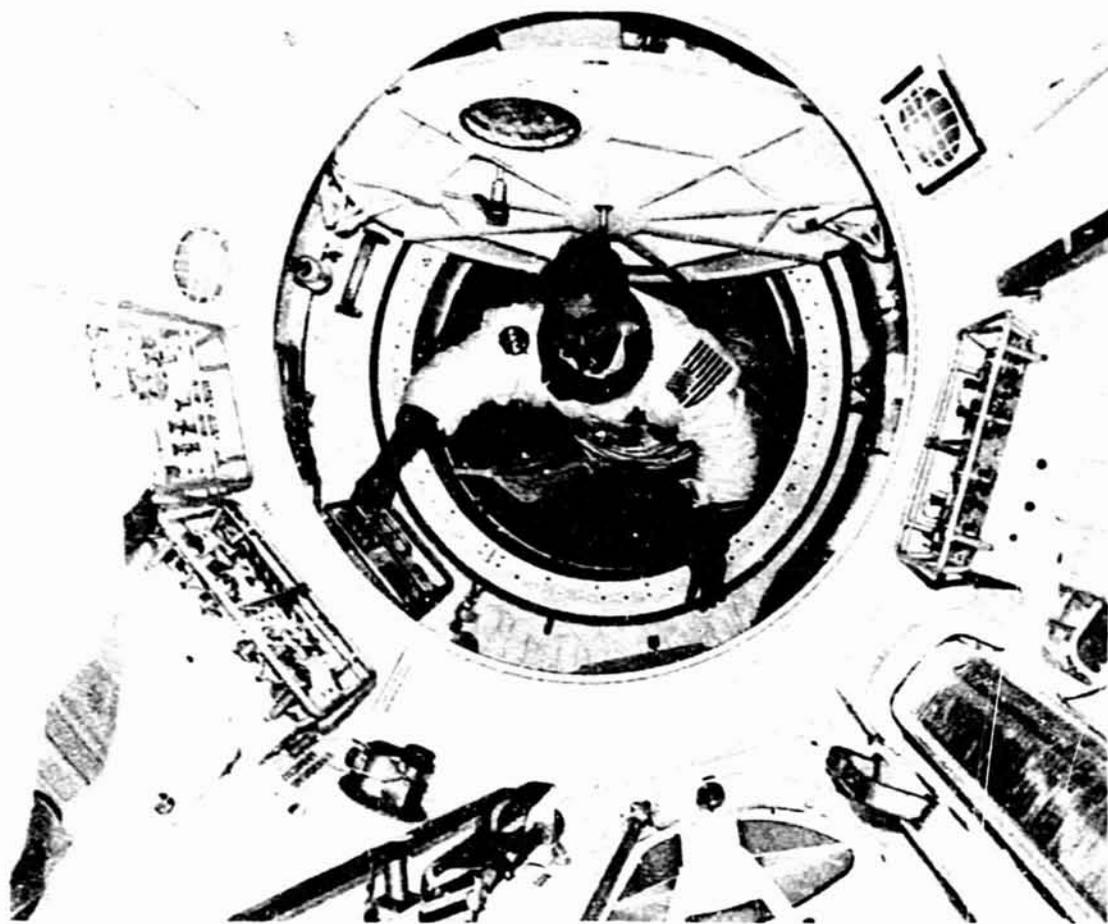


Figure 10-3.- Lock compartment entry from workshop.

Two containers provide stowage for two life support umbilicals. The aft compartment was originally intended as a separate crew station, but later became an extension of the lock compartment. The facility for recharging the maneuvering experiment propulsion supply bottles and access to the workshop heat exchanger module are contained in the compartment. The recharging assembly folds up when not in use to avoid obstructing crew movements. Shadow-free illumination is provided by four light assemblies.

The lock compartment size was considered good for extravehicular activity preparations and operations. It was large enough to accommodate the equipment and crew, yet small enough for adequate body restraint. The equipment in the compartment was well arranged for efficient use. Removal and return of the life support umbilicals were particularly easy. Hatch and repressurization valve operations were very smooth. The crewmen bumped their knees on the internal hatch sills, however, when their trajectory through the hatch opening was not perfect. The compartment also separated a main working area in the docking adapter from the main living and working areas of the workshop, requiring much additional translation.

Workshop Forward Compartment.- This is the largest station of the laboratory. Equipment located in the compartment includes the waste management

compartment ventilation fan, food freezers, the refrigeration pump unit, ventilation ducts, fans and a mixing chamber, biocide monitoring equipment, two scientific airlocks, miscellaneous lockers and stowage provisions, the film vault and photographic equipment, the large volume ring lockers, and the large food containers. Also stowed and operated in the compartment are the hardware items associated with the various scientific, technical, and medical experiments. A variety of restraints and translation devices are provided for crew mobility and stability during operations. The open floor grid on the floors of the workshop compartments provided for crewman foot restraints, attach points for temporary tethering, handholds, and communications between compartments.

The most significant fact about the forward compartment crew station was that the large volume did not present any difficulty to the crewmen in translation or mobility. Space for the performance and evaluation of the flying experiments was more than adequate. The 250-pound food boxes were easily relocated by one crewman from their floor-mounted launch position to their orbital stowage location. The mixing chamber screen provided a work table to handle small items, using the retaining force of the airflow.

Wardroom.- This is a wedge-shaped compartment on the crew quarters level (fig. 10-4). Facilities include a galley, food freezer and chiller, food table, viewing window, experiment equipment, crew entertainment center, and stowage compartments for flight data, clothing, and other supplies. A curtain is provided to close the entrance.

The wardroom proved to be a natural place for the crew to congregate and relax, in addition to being the center for food preparation and eating. The general size and arrangement of the wardroom, with the central table, proved satisfactory. There were some problems with access to the food stowage provisions, and incompatibility with the triangle shoes and light-duty foot restraints at the wardroom table. The wardroom table was used as a place to make the many flight data changes throughout the mission, but was not suitable for this task (fig. 10-5). A desk, or similar facility, was recommended for writing reports, incorporating teleprinter messages into checklists, and performing other paperwork tasks. Normally used office supplies should also be available. The wardroom window, with its changing kaleidoscope of the Earth, was an important aspect in maintaining morale, as looking out with binoculars was the most relaxing and enjoyable off-duty activity. The window also was used for hand-held photography of numerous Earth features. The location and orientation of the window proved adequate for most operations, but a desire for larger and more windows was expressed.

Waste Management.- This station is a compact rectangular-shaped room located on the crew quarters level (figure 10-6). The compartment includes a urine and fecal collection module; a sink with a water dispenser and washcloth squeezer; stowage lockers for washcloths, towels, wipes, and tissues; waste processors; a urine freezer; fecal dryer; towel and washcloth drying provisions; and necessary waste management supplies. A folding metal door is installed at the entrance.

The compartment was acceptable in size and layout for operation by only one crewman at a time. Privacy would have been desirable between waste management and personal hygiene functions. Spills and housekeeping tasks anticipated before the mission had resulted in a design using solid floors and ceilings, and the

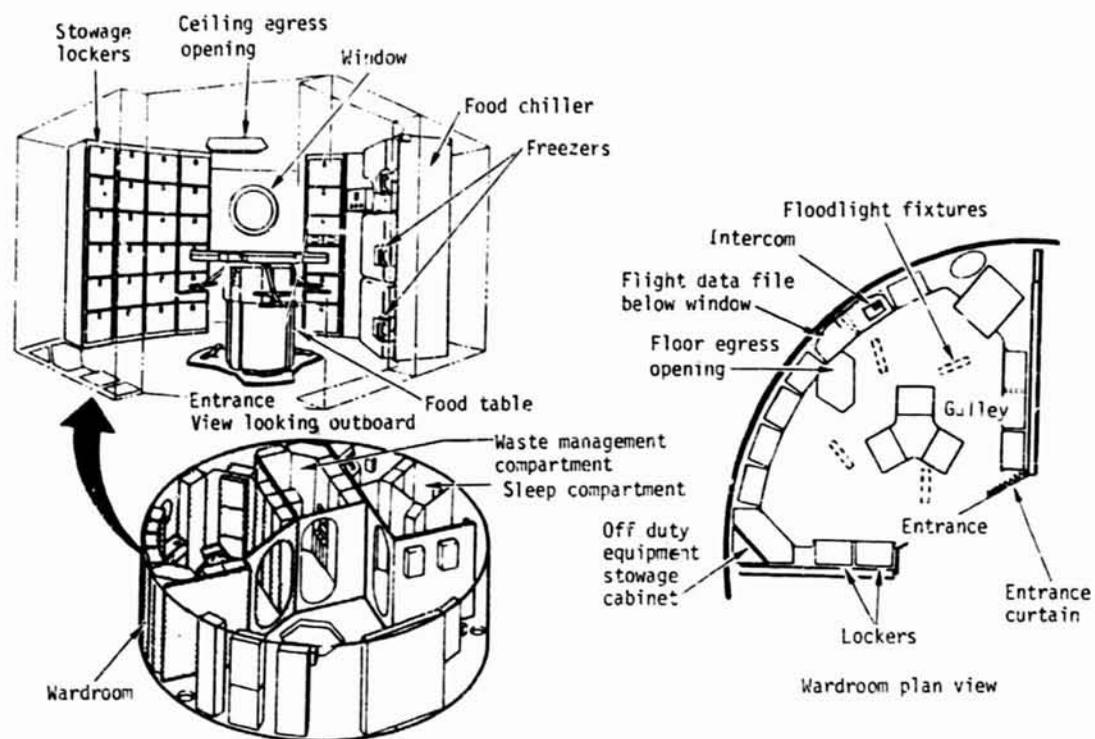


Figure 10-4.- Wardroom arrangement.



Figure 10-5.- Wardroom showing the window and a crewman working with a teleprinter message.

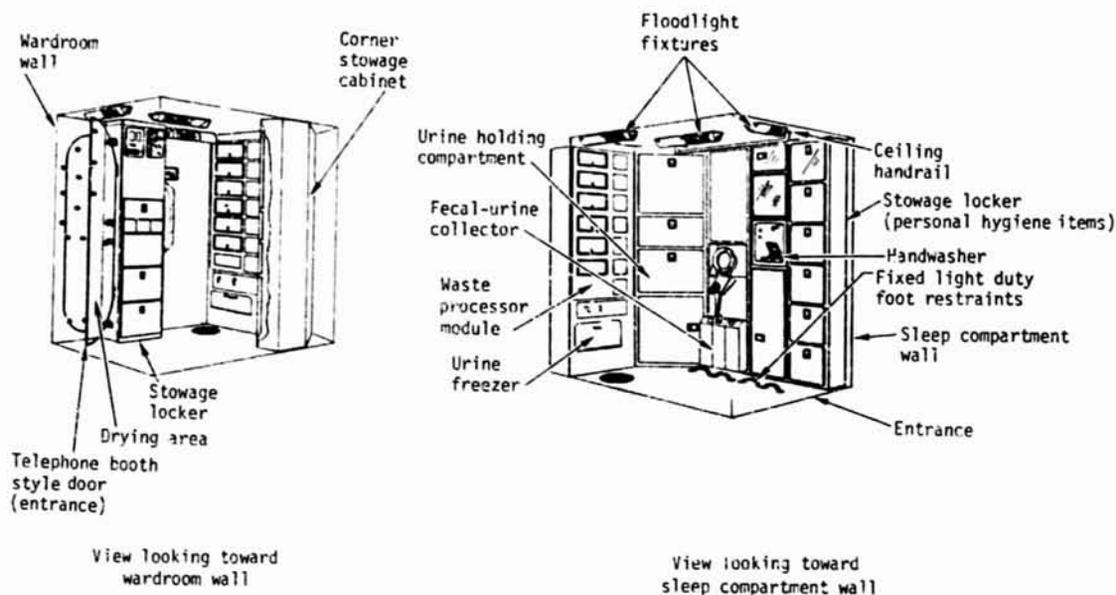


Figure 10-6.- Waste management compartment arrangement.

lack of suitable foot restraints was a problem. Since spills were not a problem, a floor of triangular grid for foot restraint compatibility would have been better.

Sleep Compartment.- Three sleeping areas (fig. 10-7) are provided on the crew quarters level. Each individual sleep area contains a sleep restraint, a light, stowage for clothing and personal items, an intercom, towel holders, and a privacy curtain. The Science Pilot's sleep area is provided with monitoring equipment associated with the sleep experiment. The sleep station was used for scheduled sleep periods or as desired for off-duty resting. There was need for more personal stowage space and temporary equipment restraints in the sleep areas. Quietness, ventilation, and personal comfort preferences varied with individual crewmen.

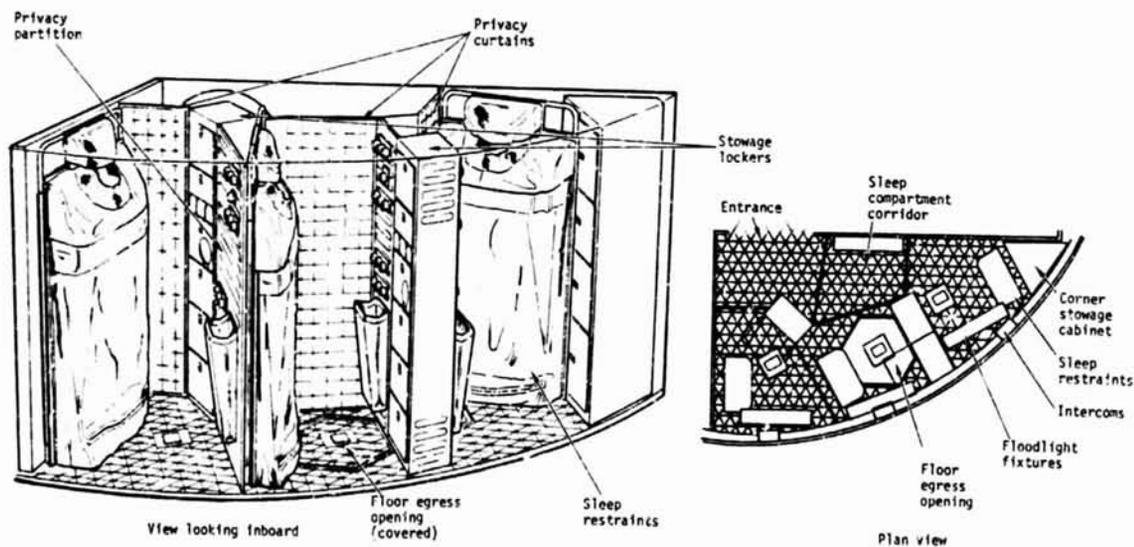


Figure 10-7.- Sleep compartment arrangement.

Experiment Compartment.- The remainder of the crew quarters level is the experiment compartment, which is semicircular in shape. The trash airlock, a large amount of medical experiment equipment, the shower, and the workshop electrical control panels are located in the compartment. Entry to the other crew quarters compartments is from the experiment compartment. Figure 10-8 shows the general arrangement of the compartment.

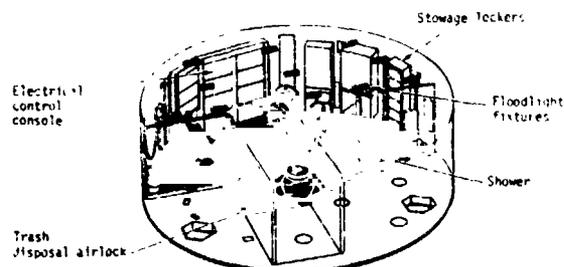


Figure 10-8.- Experiment compartment arrangement.

Layout and arrangements were adequate and the vertical orientation made experiment operations seem more like those practiced during training. Equipment was crowded in the shower area because it was added late in the program. The noise of the metabolic activity ergometer hindered communication and could be heard on the intercoms and tape recordings.

Plenum Area.- This is an irregular-shaped space (fig. 10-1) under the crew quarters floor between the outer shell and the waste tank common bulkhead. It is used for permanent stowage of biologically inactive trash. Access to the area and to individual stowage bags was satisfactory and there was no problem translating through the confined space.

#### 10.1.2 Water System

The Saturn Workshop water system includes the necessary equipment for the storage, microbiological control, distribution, and dispensing of potable water. Potable water is used for drinking, food and beverage reconstitution, crew hygiene, housekeeping, and flushing of the urine separators. Water is also provided for servicing the extravehicular activity suit support equipment, the fire hose, and certain ancillary experiment equipment. Figure 10-9 shows the arrangement of the water system components.

Water Storage.- This equipment consists of 10 stainless steel, 500-pound-capacity water tanks evenly spaced around the circumference of the workshop forward compartment. Inside each tank is a gas chamber, consisting of a dome and a sealed metal bellows. A nitrogen distribution network provides a regulated gas supply at 35 psig to the bellows to maintain the water pressure required for distribution. Each water tank can be protected from freezing during unmanned periods by an electrical heater blanket wrapped around the circumference of the tank. A 26-pound-capacity portable tank is provided for use as an emergency water supply in the event of system failure and for sterilization of the wardroom water network during activation for the second and third manned periods. The portable tank is also pressurized with gas from the nitrogen distribution network.

There was concern during the first unmanned period that the elevated temperatures in the workshop would cause the water in the tanks to expand and damage the bellows. The first crew verified the integrity of the tanks even though temperatures were approximately 130°F. After the deployment of the parasol thermal shield, the workshop temperatures began to drop, and the tank temperatures became normal within a few days. The tank heaters were not used during the mission. Activation and operation of the nitrogen distribution network created no problems.

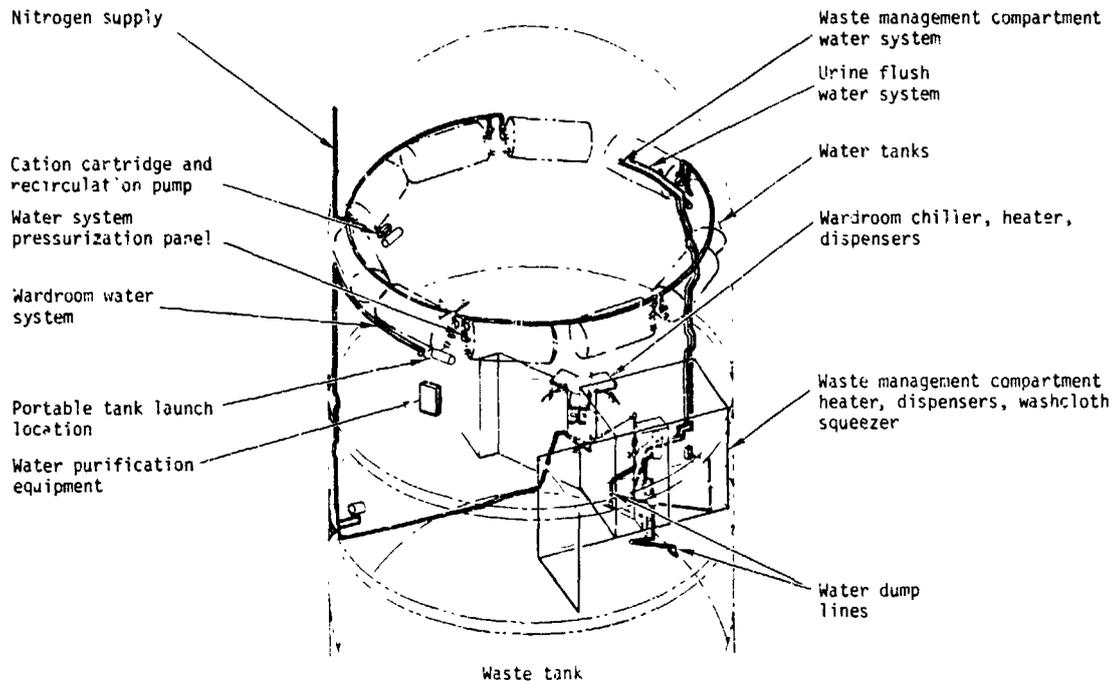


Figure 10-9.- Workshop water system.

Water Purification.- Equipment is provided for sampling, analyzing, and purifying the water using iodine as a biocide. The water purification equipment consists of water samplers, reagent containers, iodine injectors, iodine containers, a color comparator, a waste sample container, and a cation cartridge. Each of the 10 water tanks is charged before launch with an iodine concentration of 12 ppm. The crew periodically samples the iodine levels and determines the amount of iodine required to keep the level above 2 ppm. The portable tank is precharged with iodine to provide a concentration of 100 ppm when filled with water. This solution is injected into the wardroom water distribution system as a biocide soak during activation for the second and third manned periods. A deionization cartridge, containing approximately 66 in.<sup>3</sup> of ion exchange resin, is provided to remove metallic ions from the potable water.

During activation of the water system, the first crew reported iodine concentration levels very close to zero. After the initial replenishment, the iodine levels in the tanks remained above the predicted depletion rates. Of the 2760 cm<sup>3</sup> of iodine solution provided, a total of 530 cm<sup>3</sup> was injected into the water system during the mission. Each crew returned water samples for analysis and the results of these analyses are presented in table 10-I.

Water Distribution, Wardroom.- This system consists of a flex line from the selected water storage tank connected to a hard line running from the tank area to the wardroom table. In the table, the line branches to a heater and chiller. The heater is connected to a food and beverage reconstitution dispenser extending through the top of the table. The chiller is connected to a food and beverage reconstitution dispenser and three individual drinking guns. A water dump system is provided for evacuating the fresh water supply lines

Table 10-I.- Returned Water Sample Analysis Results

Analysis performed	Limits	First manned period	Second manned period	Third manned period
<b>Ionic species levels (mg/ml)</b>				
Cadmium	0.01	0.01	0.01	0.026
Calcium	5.6	--	0.1	40
Chromium (hex)	0.05	0.01	0.02	0.035
Copper	1.0	0.05	0.01	0.005
Iron	0.3	0.1	0.29	0.26
Lead	0.05	0.05	0.02	0.05
Manganese	0.05	0.01	0.01	0.03
Mercury	0.005	0.005	0.005	0.0005
Nickel	0.05	0.05	0.03	0.07
Silver	0.05	--	0.02	0.005
Zinc	5.0	0.11	0.02	0.01
Iodide	Reference	25	33.4	18.5
Selenium	Reference	0.01	--	0.01
Iodine		0.5	0.05	1.0
Silicon		0.5	0.5	0.24
Potassium		7.0	8.8	5.9
Magnesium		0.5	0.5	2.5
Sodium		0.1	1.74	0.62
Arsenic		0.1	--	0.05
Aluminum		0.5	0.5	0.05
<b>Properties</b>				
Electrical conductivity, microhm/cm at 25°C	Reference only	36	32	310
pH (at 25°C)	4 to 8	4.6	4.8	7.8
Turbidity (Nephelos units)	11	9	5	17
Color true, units	Reference only	1	5 to 10	--

during filling and biocide flush operations and for draining the lines during deactivation. The waste water is transferred to the waste tank through a replaceable heated dump probe, which prevents blockage due to ice formation. Figure 10-10 is a schematic representation of the system.

The wardroom water system equipment was used by the crew as planned and operated successfully. Because of the chilling, there was no noticeable iodine taste in the water. Usually, the fourth shot from the drinking dispenser provided the coldest water. No condensation problems with the chiller were noted. A suspected leak on the food reconstitution dispenser was merely blow-by which tended to collect on items with small radii, giving the appearance of being a leak. The crew recommended increasing the dispensing volume to 8 ounces instead of 6 ounces, since many of the beverage packs required 8 ounces of water. The food reconstitution dispensers were considered adequate, and the water drinking guns were "... an excellent piece of equipment."

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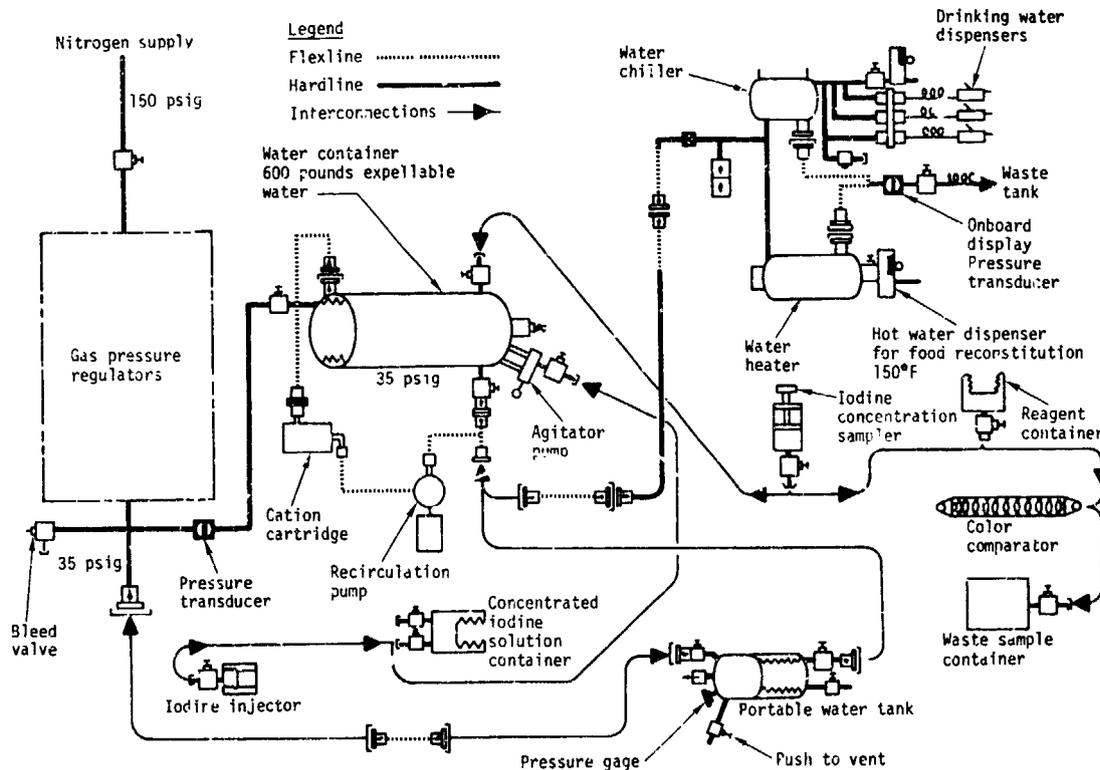


Figure 10-10.- Wardroom water system schematic.

Water Distribution, Waste Management Compartment.- This system consists of flex lines at the selected water storage tanks connected to a hard line network that supplies water to the compartment water heater and urine flush system. The heated water is released through a dispenser and used for personal hygiene purposes in conjunction with washcloths, towels, and the washcloth squeezer. The urine flush system dispenser is capable of dispensing 50-milliliter increments of iodine to flush the urine separators if microbiological tests indicate a need. A water dump system is also provided for servicing the water system lines, for dumping the waste wash water collected in the washcloth squeezer bag, and for dumping the laboratory atmosphere condensate tank. A schematic of the waste management compartment water system is shown in figure 10-11.

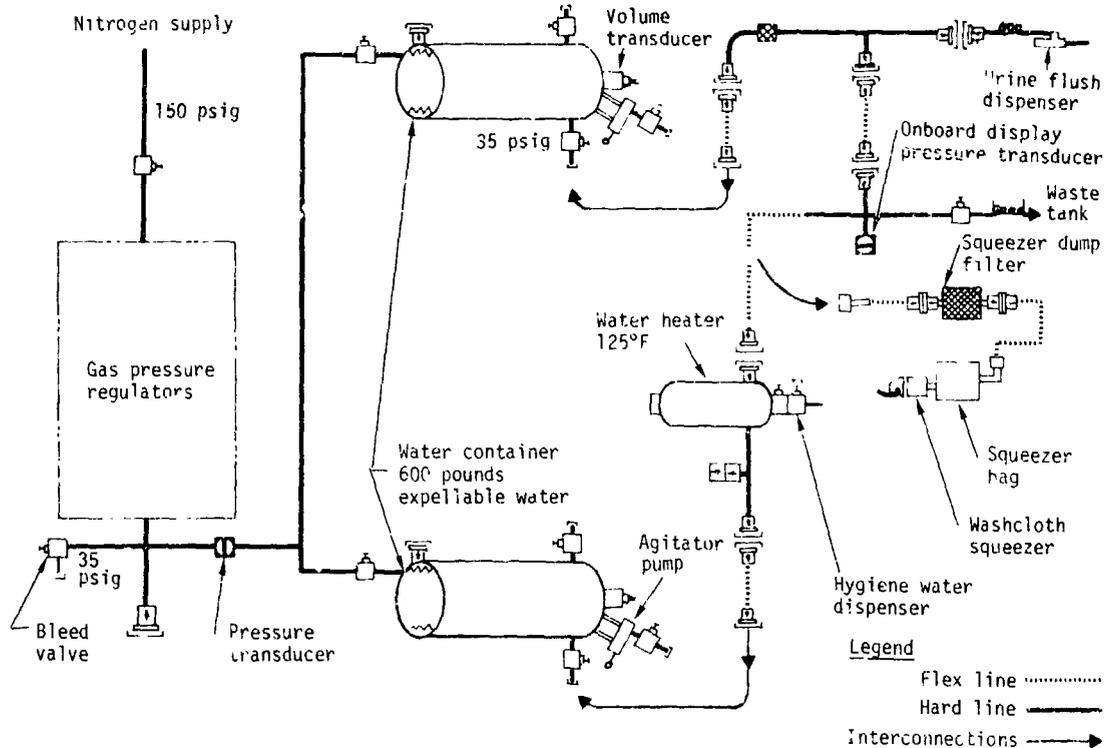


Figure 10-11.- Waste management compartment water system schematic.

Only two problems occurred with the waste management water system. The water dump system operated very slowly and in some cases did not drain completely during the second manned period. This was indicative of partial blockage in the heated dump probe. Efforts to clear the blockage were unsuccessful, and the probe was replaced with a spare unit. The crew found ice in the removed probe tip, but an electrical continuity test ruled out the possibility of heater failure, so the cause of probe freezeup is not known. No difficulty was encountered with the new probe. The hot water dispenser valve was replaced with a spare unit when a decrease in flow was noted. The water dispensing and collection equipment was considered well-designed. Installation of the squeezer bag was no problem. The water bag dump was performed approximately every 3 days, when the bag was about two-thirds full. The urine flush system was not required during the mission.

Table 10-II.- Pre-mission Water Tank Allocation

Tank number	Usage
1	First wardroom tank, first manned period
2	Third wardroom tank, second manned period
3	Fourth wardroom tank, third manned period
4	Fifth wardroom tank, third manned period
5	Sixth wardroom tank, third manned period
6	Urine flush, reserve, fire hose
7	First waste management tank, first and second manned periods
8	Second waste management tank, second and third manned periods
9	Reserve for wardroom or waste management and extravehicular activity suit loop
10	Second wardroom tank, second manned period

Table 10-III.- Water Budget

Function	Maximum 3-crew use rate	Requirement, pounds
Metabolic tanks		
Command module return	24 lb/manned period	72.0
Metabolic	22.5 l./day	3029.4
Wardroom system bleed (end of manned period)	15 lb/manned period	45.0
Wardroom system microbiological flush (start of manned period)	21 lb 1st manned period 98 lb 2nd and 3rd manned periods	137.0
Iodine sampling		0.5
		3282.9
Waste management compartment tanks		
System bleed (end of manned period)	7.5 lb/manned period	22.5
Housekeeping	4 lb/day	544.2
Personal hygiene	3 lb/day	409.8
Shower	6 lb/shower (1 shower/manned period)	360.0
Iodine sampling		0.3
		1336.8
Urine separator tanks		
Urine flush	600 ml/day	130.5
Urine separator bleed	7.5 lb/manned period	10.5
Life support umbilical reservicing		34.8
Solar observatory console recharge		24.0
Condensing heat exchangers reservicing		3.9
M479 extinguishing		1.3
Iodine sampling		0.1
		254.9
Total requirement		4874.6
Margin		104.4
Unusable		660.0
Total onboard		5219.0

Water Management.- This function involves the actual loaded and expellable amounts of water, the allocation of water storage tanks for specific functions, and the manner in which water is used by the crew. Approximately 6580 pounds of water is loaded onboard, of which approximately 5920 pounds is expellable. The pre-mission allocation for the various Skylab water tanks is shown in table 10-II. Table 10-III shows the water budget planned before the mission for the wardroom and waste management compartments, along with other Skylab system requirements.

There were no problems associated with water management during the mission. The crewmen used a total of 3990 pounds of water (less than allotted), although they drew 60 pounds of water from tank number 7 through the water heater into the waste tank in an attempt to thaw the waste management compartment water dump probe. The only water used from tank number 9 was for servicing the life support umbilicals before extravehicular activities. Figure 10-12 shows the water used during the mission and the amounts remaining. Individual drinking water consumption was recorded daily, and the amount used by each crewman is presented in figure 10-13. Liquids were available, however, from other sources such as soft drinks, so that figure 10-13 does not represent the total fluid intake. This and differences among individuals could account for the considerable differences shown in the water consumption of the crewmen. The Saturn Workshop system of water storage, pressurization,

transfer, and general management was completely satisfactory, and is feasible for a water system where weight is not a critical problem.

### 10.1.3 Waste System

The waste system samples, processes, and stores all crew metabolic wastes, including feces, urine, and vomitus. It provides a means for the crew to perform fecal and urine eliminations, to sample and preserve the material for biomedical analysis upon return, and to dispose of the remainder. The system consists of a fecal-urine collector, collection and sample bags, sampling equipment, odor control filters, a blower, and other necessary supplies. The components are located in the workshop waste management compartment (fig. 10-14). A functional

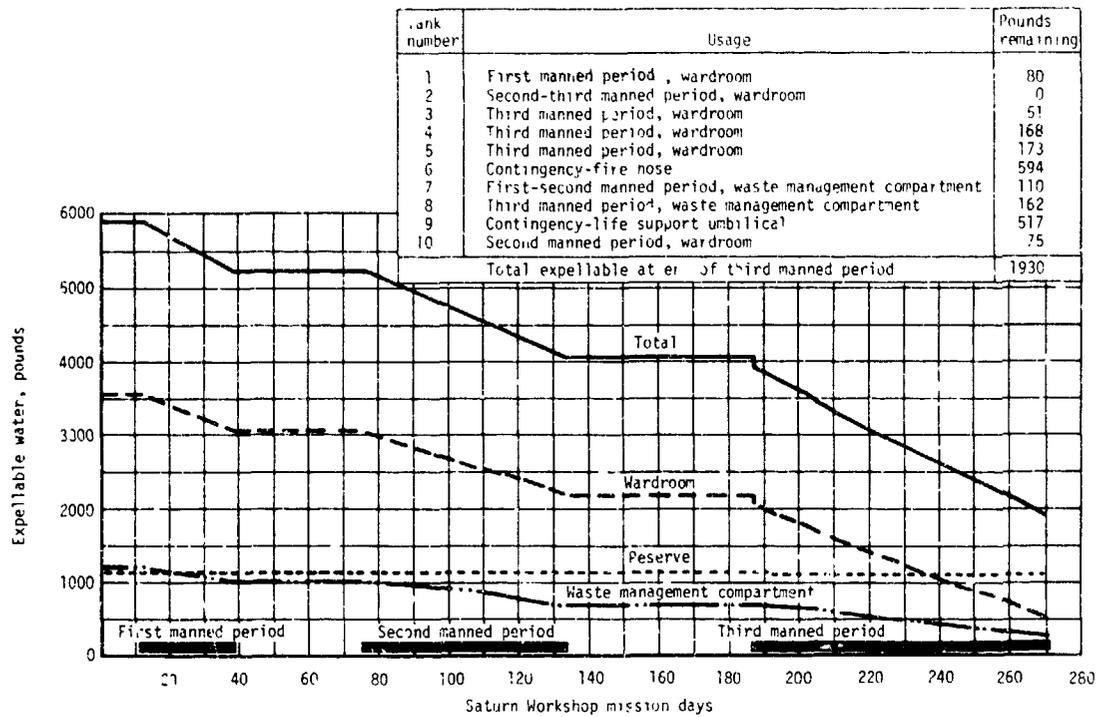


Figure 10-12.- Water usage.

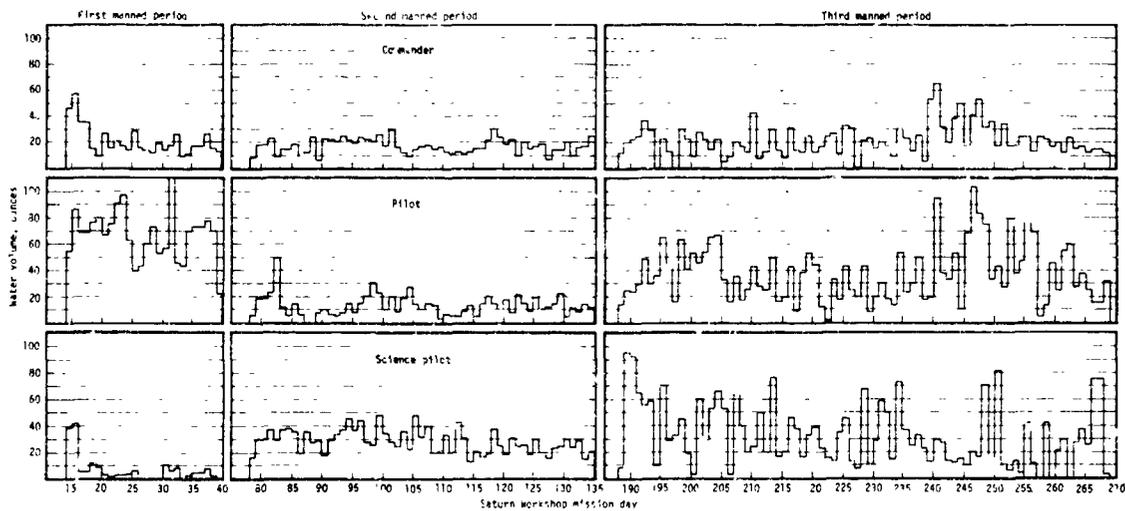


Figure 10-13.- Individual drinking water consumption.

schematic of the waste system is shown in figure 10-15. The fecal-urine collector (fig. 10-16) provides for the collection of both feces and urine, using air-flow as a substitute for gravity to separate the waste material from the body. Urination may be performed in a standing or seated position, and urination and defecation may be performed simultaneously while seated.



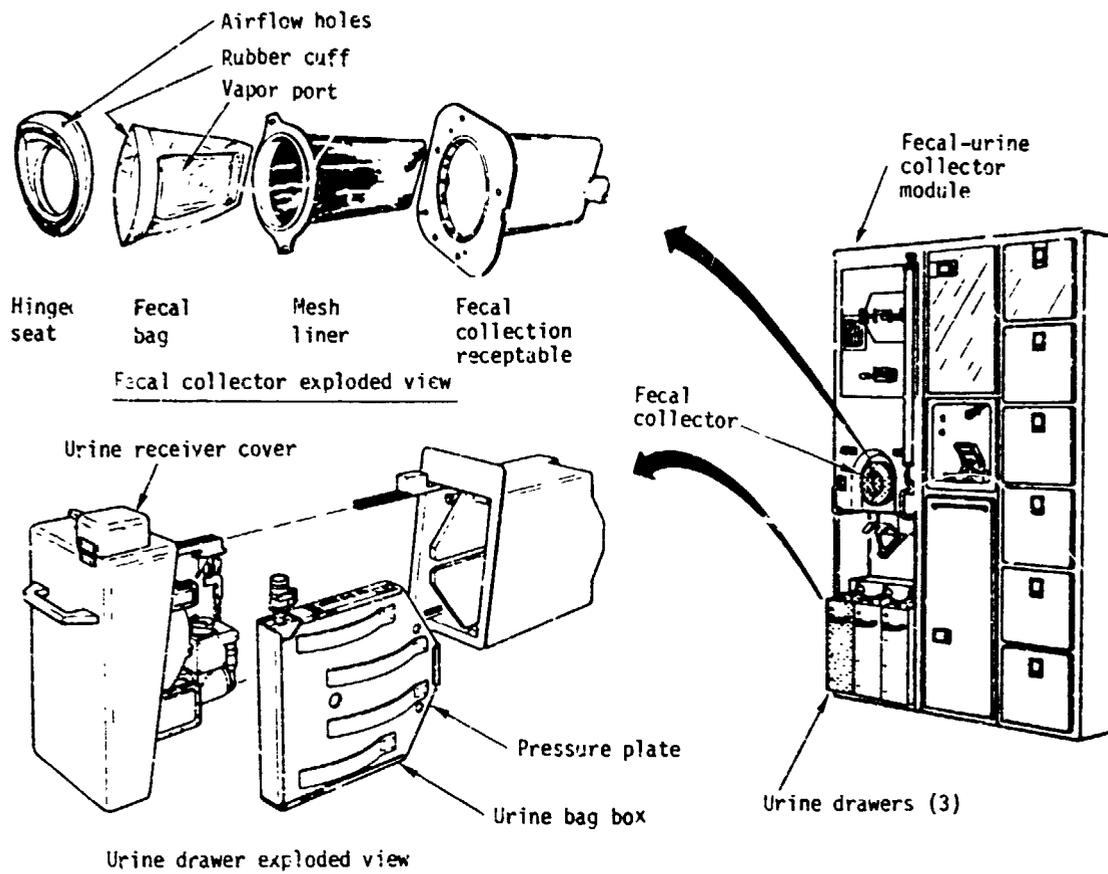


Figure 10-16.- Fecal-urine collection hardware.

environment, a lap restraint belt, handholds, and foot well restraints are provided so the crewman may maintain a sufficiently tight seal on the seat. Airflow from a blower separates the fecal matter from the body and retains it in the fecal collection bag. The bag is then sealed for waste processing. A separate fecal bag is used for each defecation. An articulating mirror is provided as a cleanup aid for the crewman.

The crew used the fecal collector as the primary mode of collection during the mission. The fecal collection equipment worked successfully and the crew expressed general satisfaction. The geometry of the fecal collector was satisfactory, except that the crew did not like the severe crouched position required to maintain a good seal with the collector seat.

The airflow system of collecting feces was a good concept and worked exceptionally well; however, it was felt that higher airflow would provide even better results. The crew recommended that for longer missions, the seat be fabricated from a softer material and the outside diameter widened, making it easier to obtain a good airflow seal. The hand grips were always used to provide the pulling force necessary to attain a proper seal. The airflow did not become uncomfortable and bolus separation was obtained in most cases. There was an average of one fecal collection every 2 days per crewman. Controls and wipes were readily accessible and there were no difficulties in wiping. Approximately

two wipes were used for each defecation and placed in the fecal bag. A wet washcloth was used for final cleaning and disposed of in the urine disposal bag. The crew indicated that the articulating mirror was necessary and always used. The collector seat did not become dirty, and odor control was satisfactory.

The fecal bags sustained no damage during use. Minor difficulties were encountered while installing the bag's inner cuffs in the fecal receptacle, and several of the black rubber outer cuffs came loose from fecal bags. These bags were discarded. Bag sealing was always done with the blower running, and although no seals leaked, the crew commented several times on the "unforgiving" sticky adhesive used. The time required for bag sealing, mass measuring, and processor loading was not considered excessive. One crewman recommended longer bags.

Fecal collection using the contingency fecal bags was accomplished on several occasions. As in the Apollo missions, cleanup after using the paste-on contingency fecal bag required excessive wiping. It normally took the crew approximately 1 hour to perform the contingency fecal collection. Although no recommendations were made, it was clear that the crew was not satisfied with the contingency fecal bag. Since it was used infrequently and there is no obvious substitute, they could only convey their dissatisfaction. The contingency fecal bag was also satisfactorily used to collect vomitus. A small amount of vomitus around the opening was removed with tissue and the bag sealed. A summary of expendable fecal collection equipment used during the mission is shown in table 10-IV.

Table 10-IV.- Fecal and Urine Collection  
Expendable Items Usage Summary

Item	Quantity onboard at launch	First manned period			Second manned period			Third manned period			Remarks
		Expected usage	Actual usage	Total remaining	Expected usage	Actual usage	Total remaining	Expected usage	Actual usage	Total remaining	
Fecal bags	363	84	48	41*	168	145	282	168	192	90	*As required
Contingency fecal bags	185	*	1	184	*	7	177	*	0	177	
Urine collection bags	432	34	75	360	168	178	165	168	195	2	Includes 3 bags carried by the first and second crews
Urine sample bags	375	66	63	312	132	129	204	132	204	0	
One-half urine sample bags	125	18	21	104	36	71	33	36	53	0	Includes 20 bags carried by the third crew

Waste Processor.—Drying of crew feces and vomit bags, pressure suit desiccants, and film vault desiccants is done in the waste processor. The six independent chambers (fig. 10-14) use mechanical pressure, an electrical heating element, and the waste tank vacuum to evaporate the water and dry the material, thus preventing bacterial growth. Each sealed fecal bag is placed in one of the top four chambers after the mass is determined on a specimen mass measurement device. Drying time is determined from a chart on the mass measurement device, which correlates mass of the specimen with the required drying time. In the event the mass cannot be determined, a processing time of 20 hours for normal specimens (0 to 200 grams) is used. When the chamber is opened to the waste tank vacuum, gases escape from the fecal bag through a vent port in the bag. Although the system is designed to reduce drying time by heating at approximately 105°F, feces may be processed without heat by simply extending the drying time. Overdrying does not compromise the biomedical analysis. The dried fecal bags are stored in bundles for return and do not require refrigeration. The lower two chambers in the processor are reserved for drying the pressure suit and film vault desiccants.

The waste processor performed as designed. No problems were encountered in insertion or removal of the fecal bags. Drying time generally ranged from 26 to 48 hours; a few bags were left in the processor as long as 4 days. The pressure readings were always less than 0.2 psia during processing, and the samples were acceptable for biomedical analysis. Each suit-drying desiccant required approximately 10 hours drying time. The processor chamber failed to evacuate on two occasions while drying a suit desiccant. The crew determined that the thickness of the desiccant held the filter saver valve in a closed position over the vacuum port. These two desiccants were replaced and no further problems were encountered. Since there was no noted difference between fecal specimens dried with or without heat, the electrical heating system was probably unnecessary.

Urine Collection.- Two modes of operation are used for urine collection in the laboratory. The first uses airflow as a gravity substitute to draw urine through a receiver and hose into a urine collection bag. The second mode incorporates a roll-on cuff method of collection, using the urine bag directly, without airflow. Urine is also collected during pressure-suited operations by the Apollo-type urine collection and transfer assembly. Each crewman is provided a urine collection system contained in one of three drawers mounted in the fecal-urine collector (fig. 10-16 and 10-17). The crewman urinates into an inlet cone which is connected by a receiver hose to a centrifugal urine-air separator. The urine is carried into the urine separator by airflow from the same blower used for fecal collection. The motor-driven urine separator collects urine and cabin air, and the spinning action of the vanes propels the urine to the periphery of the separator through centrifugal action (fig. 10-18). The cabin air exhausts through a replaceable hydrophobic filter in the center of the separator to the fecal-urine collector filter and blower. The urine passes through a peripheral pickup tube and outlet line into the urine bag, where it is temporarily stored. The accumulation of urine is refrigerated by a cold plate type chiller which keeps the urine at approximately 60°F. A heat sink plate, mounted on the top and bottom of the separator housing, contacts the urine chiller to cool the separator before urine collection. Chilling also prevents the separator from increasing the temperature of the stored urine during the separation process. A separator and separator filter are provided for each crewman. They are installed during activation and removed at deactivation for each manned period. The urine cuff method of collection is used as a backup mode if the separator and blower are not available. The cuff adapts to a urine bag (fig. 10-18) and urination is accomplished directly into the cuff's flexible boot. Each urine collection bag has a capacity of 4 liters and is changed every 24 hours. At the end of this daily cycle, the urine volume of each crewman is measured, a sample is extracted, and a replacement bag is installed in each urine drawer. The volume of the urine is measured with the volume measuring plate, which attaches to the urine bag box (fig. 10-19). A lithium chloride tracer, contained in the urine bag, is mixed with the urine to provide a means of volume determination upon return to the ground. To obtain a urine sample, the urine bag is placed in the squeezer device and connected to a hose attached to the sample bag. The sample bag is placed in the crimper-cutter mechanism and filled by squeezing the urine bag. The interconnecting hose is cut and crimped, and the 120- to 130-milliliter sample is then frozen in the urine freezer so that it may be returned to Earth for biomedical analysis.

The centrifugal urine collection system was used as the primary collection method, and it appeared adequate. Low airflow was reported in the urine receiver

- |                           |                             |
|---------------------------|-----------------------------|
| A. Urine bag squeezer     | F. Fecal collector          |
| B. Volume measuring plate | G. Hand holds               |
| C. Water module           | H. Foot restraints          |
| D. Articulating mirror    | I. Urine collection drawers |
| E. Urine receiver holder  | J. Utility restraints       |

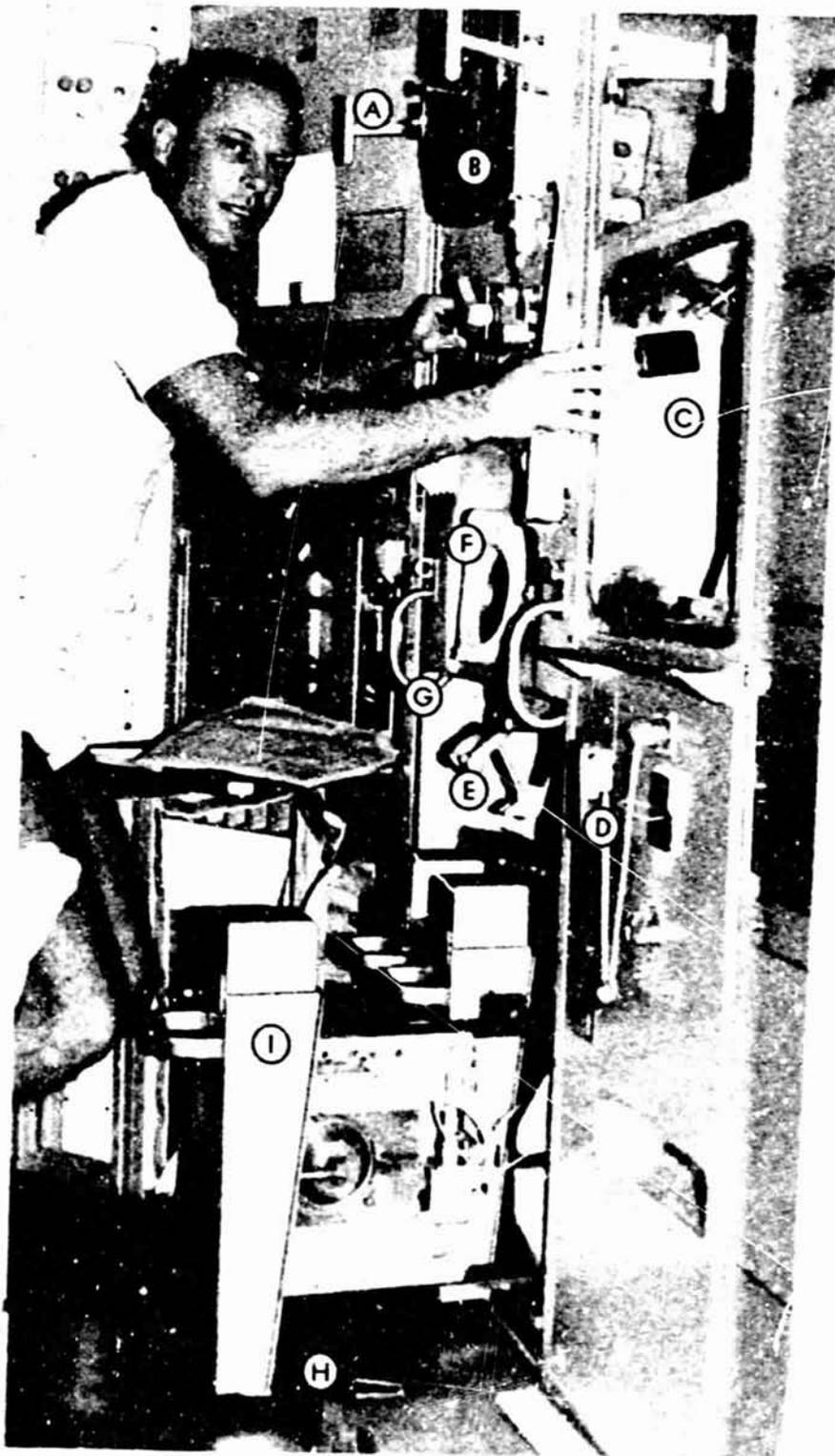


Figure 10-17.- Fecal-urine collection module.

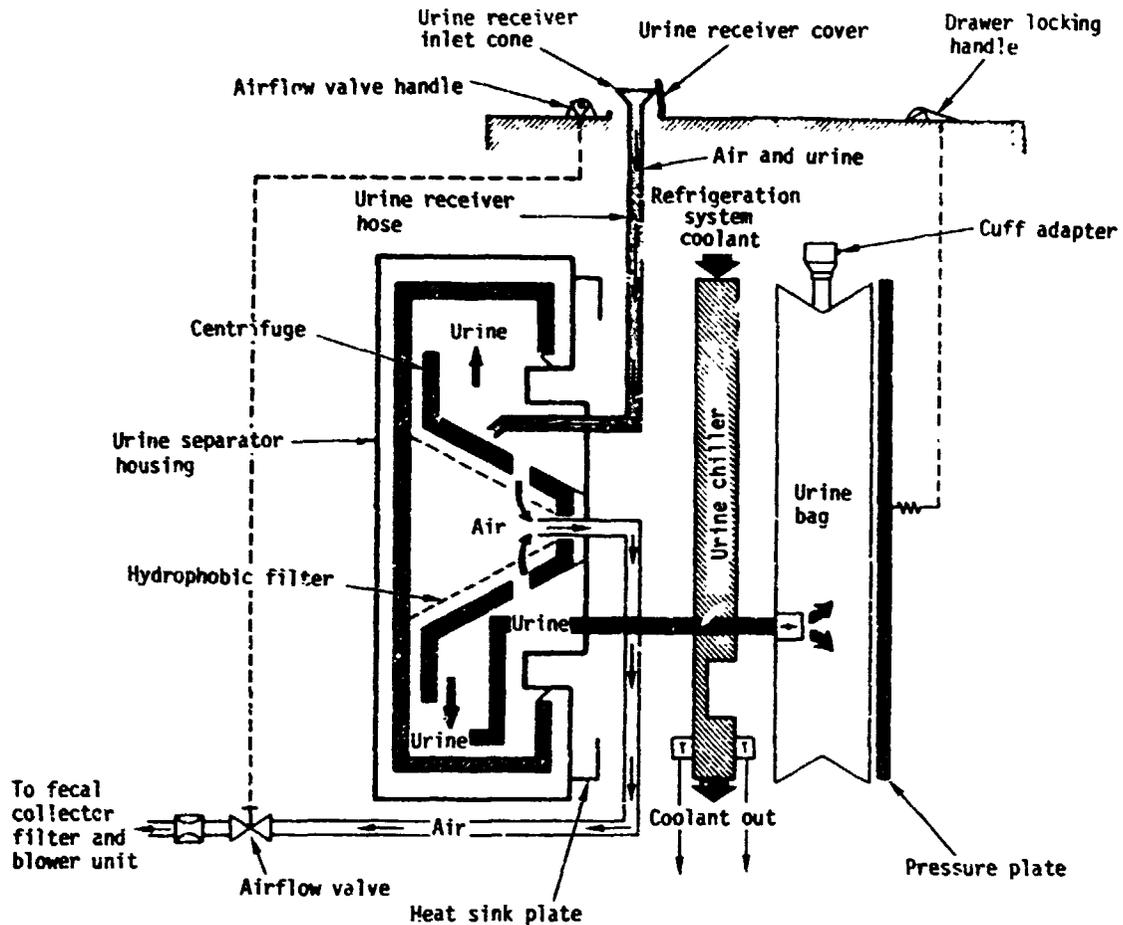


Figure 10-18.- Urine drawer schematic.

during its first use. This was corrected by installing a fecal bag in the fecal receptacle to provide the proper airflow pressure differential between the fecal and urine collection receptacles. Low airflow was reported once in urine drawer 3, and changing the separator filter restored normal airflow. During the scheduled replacement of a centrifugal separator at the end of the second manned period, the crew found that a suction line seal had separated from the line. Examination of a returned photograph revealed that the seal became debonded from the suction line flange, and a repair kit containing a stainless steel insert was flown with the third crew.

Airflow was considered adequate, and the time required for urine collection was not excessive. Noise level of the urine separators was not disturbing except during sleep periods, when the overall noise level in the laboratory was relatively low. One change in procedure became obvious to the crew. It was more suitable in zero gravity for a crewman to hold the urine receiver cone in his hand and to float freely while urinating in the standing position than to leave the cone in the fixed receiver holder on the wall. The crewmen, as a general practice, wiped the excess urine from the receiver with tissue after each use.

Condensation in the urine drawers was minimal and confined to the chiller plate. The condensation was removed by wiping daily. Occasionally, the urine

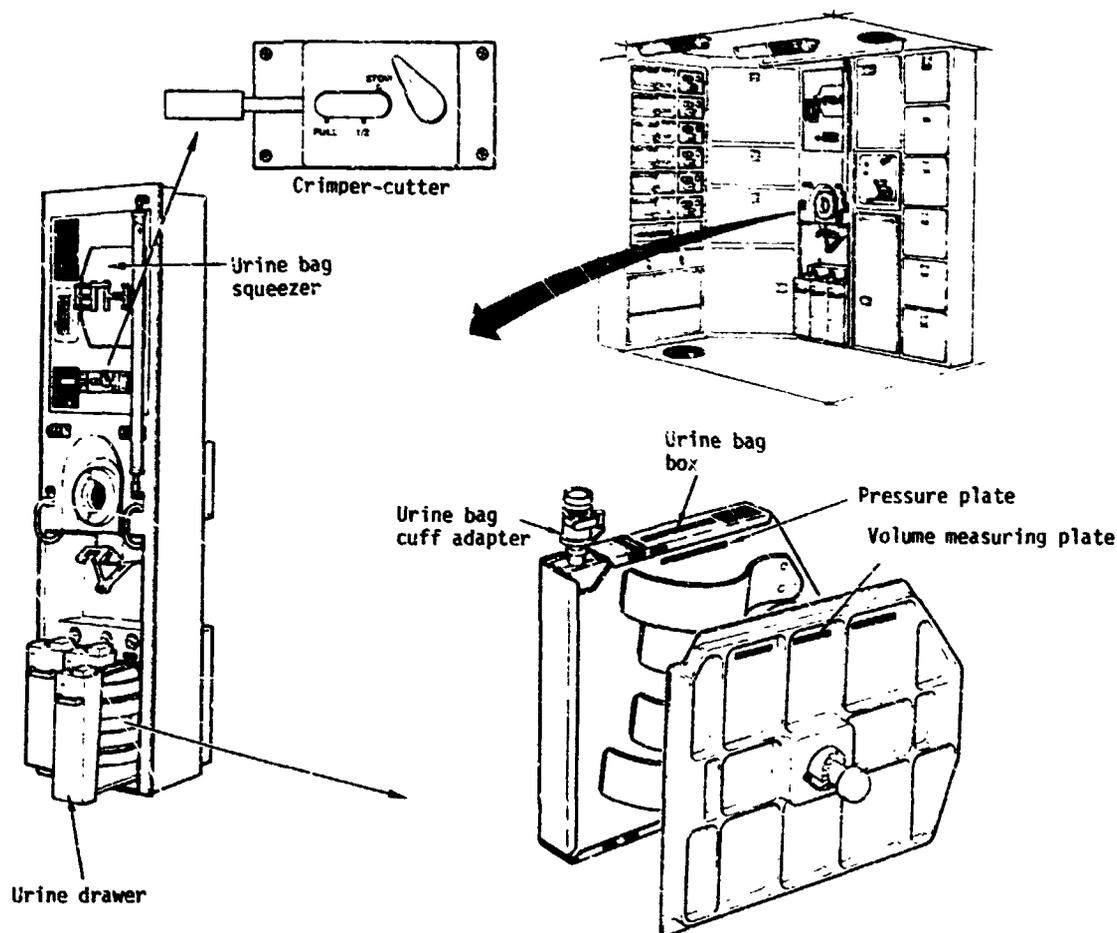


Figure 10-19.- Urine collection and sampling equipment.

hoses were pinched when caught behind the separator motor. This was eliminated by properly positioning the hose before closing the drawer. The separator motors were removed as planned at the end of each manned period, and no motor failures occurred. The urine collection water flush system was never required. The only evidence of urine odor from the collection system occurred late in the third manned period and indicated a failure in the odor control filter. The filter, which was designed for 28 days of operation, had been used for 51 days. The crew changed the filter, but during the last week of the mission the odor increased, indicating that the problem was in the blower. The blower was not replaced, although spares were available onboard.

There were no crew comments on donning the roll-on cuff for urine collection. There was no physical discomfort due to back pressure when using the cuff. The most adverse comments concerned residual urine remaining on the roll-on cuff, which caused fingers to become wet with urine during each use. Handling of the loose bag during collection and installation in the drawer was not mentioned; however, none of the bags were damaged or leaked. No changes in procedure were mentioned which would improve roll-on cuff collection.

No significant problems were reported relative to urine processing, sampling, and urine bag replacement, and only minor urine spills occurred during

the mission (10.1.7). The daily sampling and urine bag replacement required between 15 and 20 minutes. Each crewman normally performed his own sampling. When removing the urine bag box from the urine collector drawer, disconnecting the urine bag inlet boot from the separator outlet tube always resulted in some urine drops, which were wiped off with a tissue. The crew found it very difficult to use the pull tab on the urine bag to draw the urine from the separator outlet. There was no evidence of leakage back into the separator from the urine bag check valve.

The urine volume in the returned sample bags was lower than expected, averaging about 90 to 100 milliliters. During sample extraction, all crewmen noticed small air bubbles entrapped in the sample. These were most evident during the first manned period, since the second and third crews used several techniques which reduced the amount of air entrapped. Some of the crewmen swung the two connected bags like a centrifuge, and others sloshed the bag slowly while squeezing it in attempts to remove the air from the urine. It is not understood where the air came from. The most likely source was the centrifugal separator, although there is no obvious reason for the separator to pass excess air. The samples obtained from roll-on cuff collection using the urine collection bag also contained excess air. There were no problems in obtaining samples from the urine collection and transfer assembly. Samples taken during the first manned period contained approximately 70 percent air. The crew did not recommend any method of reducing air in the samples, nor did they comment on the method used to squeeze urine samples from the collection assembly. There was no difficulty in crimp-cutting the sample bag tube and pushing the crimped tube into the sample bag. The crimper-cutter area around the fecal collector door did not become contaminated.

No sample bags leaked; however, some bags were damaged either during or before removal from stowage. The frozen samples were returned as planned, and none of the bags leaked upon thawing. The samples, except for those that were low in volume, appeared to be acceptable for the biomedical experiments. The accuracy of inflight volume measurement compared to postflight analysis using the lithium chloride tracer was variable. The inflight measuring system was more accurate for samples with higher volumes. The daily urine volumes measured inflight ranged between 700 and 3800 milliliters. The lithium chloride analysis yielded a similar range of volumes. A summary of expendable urine collection and sampling equipment usage is presented in table 10-IV.

Urine Freezer.- Individual crew urine and blood samples must be frozen and stored. The freezer (fig. 10-14) has a freezing chamber, urine trays, spacers, and heat sink containers. It reduces the temperature of the sample to below 27°F within 3 hours after insertion and to -2.5°F within 8 hours.

Urine freezer temperatures remained within specified tolerances for the duration of the mission, and no operational problems were noted. The third crew, however, had difficulty in inserting the frozen urine trays into the return container. The cause of this difficulty was that the sample bags had frozen above the top of the tray. The crew felt that the trays could be forced into the container, and this method was apparently adequate, as no further difficulty was reported.

Urine Disposal.- The daily accumulation of urine in excess of that required for sampling is normally disposed of by placing the urine bags and other expendables into a disposal bag and ejecting them into the waste tank through

the trash airlock. A backup liquid urine dump system is provided in the event of failure of the primary method. The liquid urine dump system is plumbed into the waste tank through a replaceable, heated dump probe, which prevents blockage due to ice formation.

The liquid urine dump system was not used during the first and second manned periods except to evacuate the urine bags before their use. However, during the extended third manned period, the shortage of urine collection bags and the problem associated with ejecting full urine bags through the trash airlock caused use of the dump system approximately 17 times to dispose of liquid urine. On Day 237, the crew, while attempting to evacuate a replacement urine bag following a liquid urine dump, could obtain no flow through the system. Since the dump probe heater was apparently operating, it was left on for several hours, and later that day flow through the system resumed. As no further problems were reported, the most likely cause of the blockage was a buildup of ice on the probe which required heating longer than normal to dissipate. The crew indicated that the heater was left on for the rest of the manned period to preclude additional problems.

Suit Drying.- Another waste management function is to remove moisture from inside the pressure suits after suited operations. The suit drying equipment consists of a blower, hoses, and desiccant bags. The suits are attached to a portable foot restraint on the forward compartment floor and suspended from the water tank ring foot restraints by a hanger strap. The blower unit forces drying air through a hose into the suit. Moisture is removed by the air and collected by the desiccant bags. The bags are subsequently dried in the lower two chambers of the waste processor.

All hardware operated satisfactorily except that the first crew reported that the blower housing was too hot to touch. The second crew left the blower storage locker door open for additional cooling and no further problems were reported. The crew stated that the suits were dried very well and that there was no odor to the suits after the drying process. The third crew found dampness and mildew on the stowed liquid-cooled garments; however, it is not known whether the dampness occurred from insufficient drying or from some stowage condition. The problems involved in removing the mildew are discussed in 10.1.7.

#### 10.1.4 Personal Hygiene

The personal hygiene subsystem provides all the supplies and equipment necessary for health and good grooming. It includes a water module for washing, a shower, mirrors, hygiene kits, and washcloth and towel drying facilities. Wipes, tissues, soap, washcloths, and towels are also provided for use with the equipment.

Water Module.- Partial body cleansing is made possible by the module hand-washer unit, consisting of a hot water dispenser valve and washcloth squeezer (fig. 10-20). The washcloth is placed in the washcloth squeezer and the squeezer handle pulled down to squeeze the excess water out of the washcloth into a bag. The water collected in the squeezer bag is drained through a squeezer filter into the waste tank through the vacuum dump system.

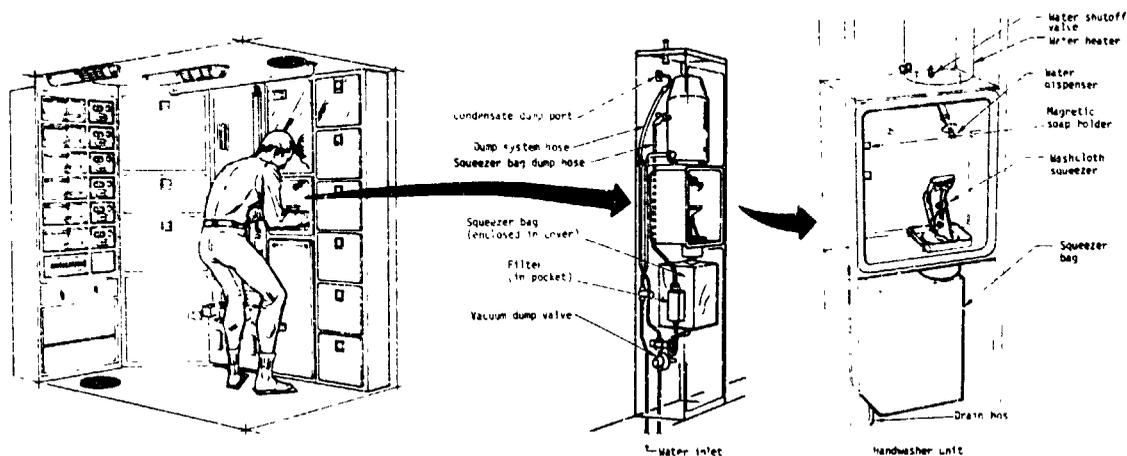


Figure 10-20.- Waste management compartment water module.

All crewmen felt that the equipment was a real necessity and that the hardware operated relatively satisfactorily. It was recommended that the handwasher unit be enclosed to contain and control the water better during washing. During the first manned period, the water dispenser valve became clogged and was replaced with a spare unit, which restored normal flow. The clogged unit was returned, and failure analysis disclosed that the wrong seal material had been used. A white, flaky residue was also found in the valve, which analysis showed to be the result of iodine reacting with a beryllium-copper retaining ring. Two reworked spare dispenser valves were sent up with the second crew, but no further failures occurred. During the second manned period, the washcloth squeezer malfunctioned. Examination by the crew revealed that the seal was folded back in at least one area, allowing water to leak past the piston. Replacement of the seal corrected the problem. The third crew also cleaned, adjusted, and lubricated the squeezer, and no further problems were reported. A double seal was recommended to eliminate the problem. The antibacterial bar soap was used at a considerably lower rate than anticipated. A total of 55 soap bars were provided, 11 for the first crew; however, only one bar was used for the entire first manned period. There is no available information on soap usage by the second and third crews.

Shower.- This is an enclosure which uses continuous airflow as a gravity substitute to move the water over the crewman. A 6-pound capacity water bottle is filled from the waste management compartment water heater, pressurized with nitrogen, and attached to the grid ceiling at the shower location. The nitrogen gas pressurant expels water from the bottle through a transfer hose and a crew-operated hand-held spray nozzle. A soap dispenser provides the crewman with 8 milliliters of liquid soap for each shower. During the shower this dispenser fastens to the ceiling with Velcro. A suction head removes water from the crewman and the shower interior. The suction head is connected by hoses to the centrifugal separator, which deposits the waste water into a collection bag. A blower pulls the air from the separator through a hydrophobic filter that protects the blower. Figure 10-21 is a schematic of the shower system.

Figure 10-22 is a photograph of the shower enclosure in a partially opened position. The crewmen agreed that taking a shower periodically was very desirable, but they all commented, to some extent, about the system. The main

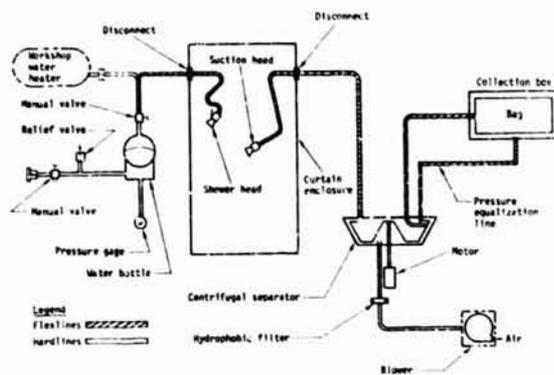


Figure 10-21.- Shower system schematic.

as prescribed. The shower system should be directly connected into the dispensing and collecting water systems to minimize crew involvement. There were also some minor comments about the liquid soap. The odor and feel after showering were considered undesirable. Toward the end of the third manned period, the liquid soap was depleted and bar soap was substituted. This may have contributed to the blower failure, as the bar soap would quickly break down the hydrophobic filter and, in time, clog the separator.

Personal Hygiene.- Unbreakable polished stainless steel mirrors are provided for personal hygiene. Mirrors are mounted in the waste management compartment to aid in partial body cleansing, shaving, hair brushing, hair crimping, and nail clipping, and one is inside the top storage compartment in each sleep area (fig. 10-23). The only adverse comment about the mirrors was that they were too dull.

One personal hygiene kit is provided for each crewman. The kits contain equipment for shaving, skin care, dental care, hair grooming, nail care, and body deodorizing. The first crew found that certain items in all of the kits were damaged by elevated temperatures in the workshop. The hand cream and toothpaste tubes had ruptured. The shaving cream container was intact, but the cream had hardened and was unusable. The damaged items were replaced by the second crew. The crew expressed a desire for a more personalized hygiene kit. There were too many items included that they had not used previously, and they desired items that were not included. Also, the kits were hard to open because of the double flap design. The crew suggested that the individual kit items should be restrained in an open area for easy access.

problem was the inefficiency of the blower and suction head. Because of the low flowrates, the cleanup of water was time consuming. On Day 263, the crew reported that the blower was inoperative, probably the result of water passing through the filter into the blower, and it was not used again. Although the water bottle functioned as designed, the crew indicated that the water cooled faster than desired. The amount of water provided was considered adequate. There were some comments about the shower curtain feeling cold when touched, and crewman reported being cold in emerging from the enclosure. The latter was probably due to not towel drying inside the enclosure

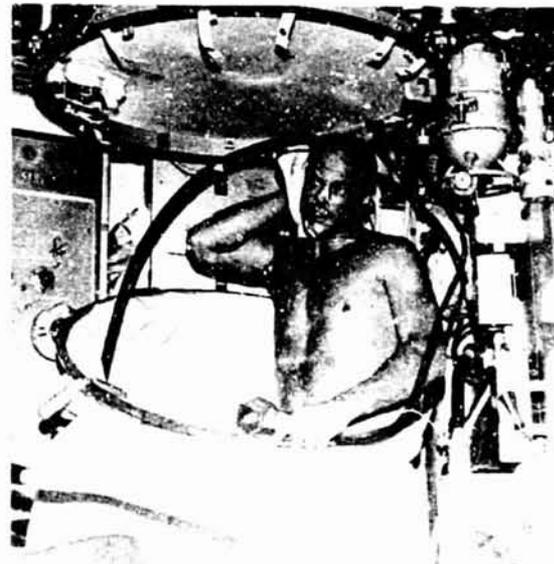


Figure 10-22.- Whole body shower.

Fluorocarbon rubber towel and washcloth drying restraints (fig. 10-24) are located in high usage and accessible areas in various compartments of the workshop. A washcloth or towel is inserted by the corner into the restraint



Figure 10-23.- Personal hygiene equipment.

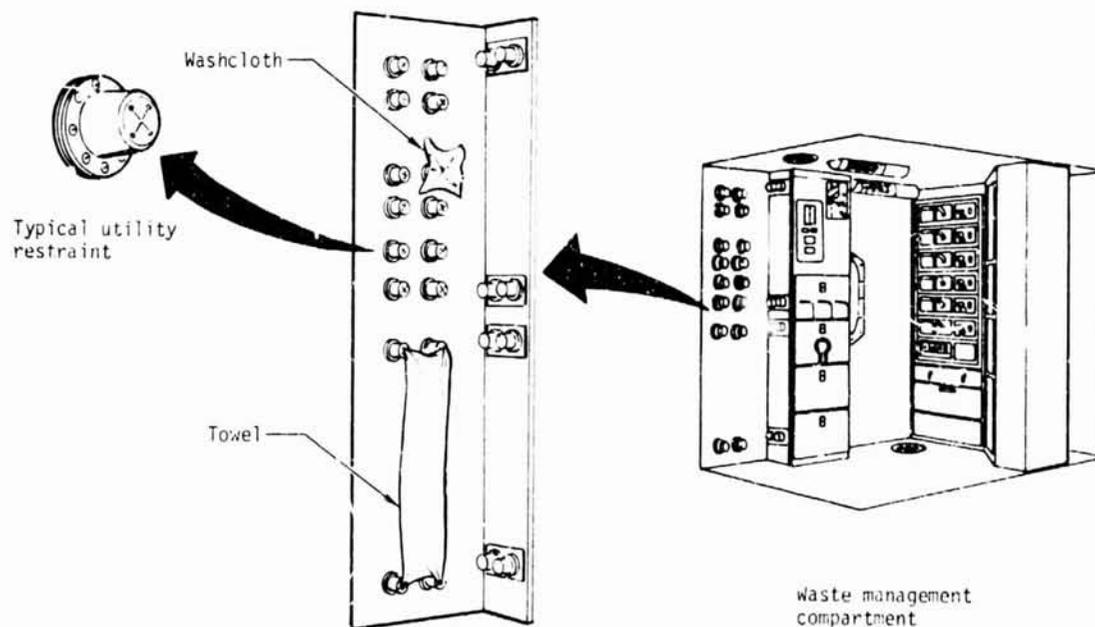


Figure 10-24.- Towel and washcloth drying restraints.

cup, and is dried by the cabin atmosphere. The drying stations provided a convenient and effective means of drying the towels and washcloths. One reported problem was that towels had a tendency to stand out from walls if restrained at only one corner, and the third crew felt that the restraints were too crowded. This type of restraint would also have been useful as a general fabric restraint.

A total of 840 reusable, 12-inch-square washcloths are provided for personal hygiene and general cleaning. They are stowed in dispensers containing 28 washcloths each. Three dispensers, one for each crewman, are located in the waste management compartment and provide a 14-day supply at a usage rate of two washcloths per day per man. Nine lockers in the wardroom contain resupply washcloth dispensers. A total of 420 reusable, 14-by-32-inch, individually rolled and banded towels are provided for skin drying. Dispenser modules, containing 18 towels each, are located in the waste management compartment and wardroom. Each module provides a 6-day supply at a usage rate of one towel per man per day. Additional towels are stowed for resupply. Both towels and washcloths are made of rayon polynosic terrycloth, with colored stitching for individual crewman color code identification.

The crew used the towels and washcloths in a normal manner for personal hygiene and for cleaning windows and wiping up spillage as well. Making the towels larger and using a more absorbent material were suggested improvements. Towel usage is shown in table 10-V. Extra towels were carried up for the third manned period.

Table 10-V.- Personal Hygiene Items Allocation and Usage Summary

Item	Quantity onboard	Allocation	First manned period			Second manned period			Third manned period			Remarks
			Expected usage	Actual usage	Total remaining	Expected usage	Actual usage	Total remaining	Expected usage	Actual usage	Total remaining	
Washcloths (each)	840	2/man/day	168	73	747	336	230	517	336	324	193	Includes 30 towels carried by the third crew
Towels (each)	420	1/man/day	84	35	385	168	85	300	168	188	142	
Utility wipes (boxes)	23 (196/box)	10 wipes/man/day plus 101	4.6	1.5	21.5	5.2	6.7	14.8	9.2	14.5	0.3	
General purpose tissues (boxes)	11 (110/box)	12 tissues/man/day plus 101	2.2	2	9	4.4	5.4	3.6	4.4	0.6	3	
Biocide wipes (boxes)	5 (70/box)	2 wipes/day plus 101	1	0.4	4.6	2	2.5	2.1	2	0.1	2	
Wet wipes (boxes)	7		1.4	0.6	6.4	2.3	1.8	4.6	2.8	0.6	4.0	

Four different types of wipes are provided: wet wipes, dry wipes, biocide wipes, and general purpose tissues. The wet wipes are used primarily for food cleanup and housekeeping. A wardroom dispenser contains seven wet-wipe packages. Dry utility wipes are used primarily for personal hygiene during fecal collection. There are 23 dry-wipe dispenser packages provided at 11 dispensing locations: 7 in the wardroom, 3 in the sleep compartment, and 1 in the waste management compartment. Biocide wipes are used for housekeeping activities that require disinfecting, such as cleaning up food spills and removing contamination in the fecal-urine system. Five biocide wipe packages are located in a single dispenser in the waste management compartment. General purpose tissues are used for general housekeeping and personal hygiene. There are 11 tissue dispenser packages: 6 in the sleep compartment, 4 in the wardroom, and 1 in the waste management compartment. Table 10-V lists the allocation and usage of the wipes.

The crew found the wipes generally satisfactory. The biocide wipes left an iodine discoloration on wiped areas, but this was not difficult to remove.

The second crew's hands became yellow as a result of deactivation cleaning tasks; however, this faded away several days after splashdown. The crew stated that they would have preferred a sponge with a handle for biocide wiping. The quantity of biocide wipes, general purpose wipes, and wet and dry utility wipes provided appeared adequate. The third crew ran out of tissues in some locations and substituted the utility wipes. They used a large number of tissues because of nasal congestion and felt that more tissues or handkerchiefs should have been provided. The second crew reported using old shirts and shorts for cleaning instead of a general purpose tissue, since cloth cleaned faster and was more pleasant to use.

### 10.1.5 Sleep

Three individual sleeping areas are provided in the sleep compartment. Each sleeping area has a sleep restraint, a privacy curtain, a light baffle, air diffusers, lights, a speaker intercom assembly, stowage compartments, and temporary stowage restraints. Figure 10-25 illustrates the sleep compartment arrangement.

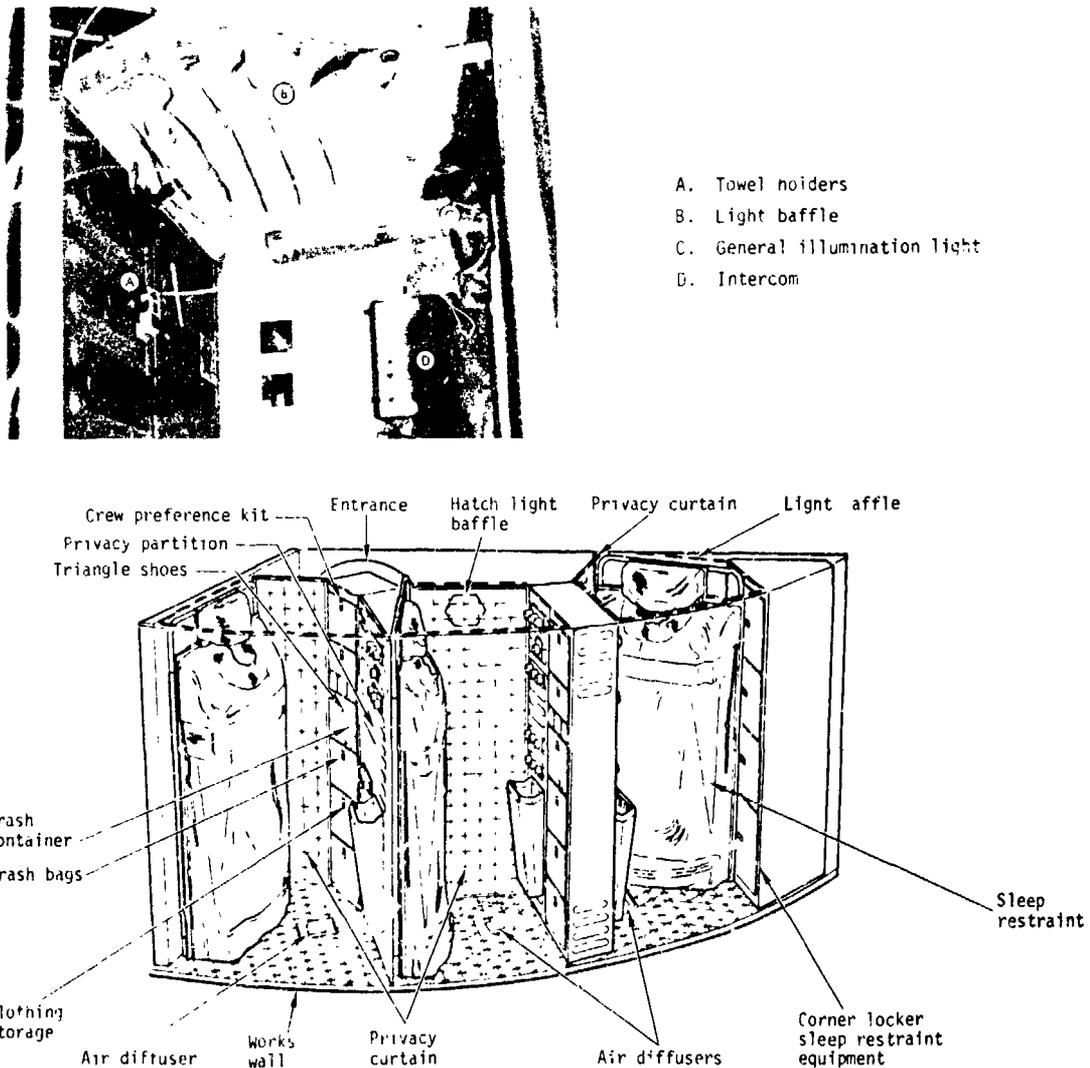


Figure 10-25.- Sleep compartment arrangement.

Sleep Restraints.- These adjustable restraints (fig. 10-26) permit each crewman to assume a sleeping position of his choice yet provide complete body restraint. They also allow reasonably rapid egress under emergency conditions. The sleep restraint consists of a welded tubular frame, a thermal back assembly, a comfort restraint, top and bottom blankets, a headrest and cover, and body straps. These components are constructed of a variety of fabric materials designed to provide the crewman a range of thermal comfort and body restraint options. The frame, thermal back assembly, and headrest are used by the crewmen throughout the mission. The remaining items are changed periodically. There are 27 additional comfort restraints, top blankets, and headrest covers stowed in the sleep compartment, providing a change every 14 days for each sleep restraint. There are 12 spare bottom blankets and large body straps and 24 small body straps to provide for a changeout every 28 days. One large and two small body straps are required for each sleep restraint.



Figure 10-26.- Sleep area and restraint.

There were no significant discrepancies with any of the sleep restraint equipment, and the crew expressed general satisfaction. The planned changeout of bedding was probably more frequent than necessary, and a reduction would improve stowage provisions and save time. The crew specifically requested that nomenclature be provided on the blankets, headrest inserts, and body straps for identification and orientation. Several crewmen suggested additional elastic straps with adjustment capability. One crewman requested an easier means of ingress and egress, although this did not appear to be a problem for the majority. On occasions, the sleep compartment was used for temporary stowage during the day, and the sleep restraint proved useful for handling bulky items such as urine bags and supply modules.

Personal comfort preferences and sleep disturbances varied with individual crewmen. Because of the meteoroid shield problem, high temperatures in the sleep compartment motivated several crewmen to relocate their restraints to cooler areas of the laboratory. One crewman inverted his sleep restraint in the compartment in order to locate his head closer to the ventilation outlet. In this position, he

could not reach the intercom and had to install a low-power portable light for reading. Another crewman moved his restraint to the forward compartment floor because he didn't like sleeping while hung on a wall. He later returned when the temperatures there exceeded that of his original sleep area. One crew hung moist towels in the sleep compartment to obtain the humidity they preferred. Noise from the waste system fecal-urine collection blower and the airlock coolant pumps occasionally disturbed sleep periods.

Privacy Curtains.- One is provided for each sleeping area to partition it off from the other sleep areas. The Teflon-coated glass-fabric curtain is stowed against a locker or wall when not in use. The curtain also serves as a barrier to block light coming from other sources. It is not, however, designed to block or reduce sound entering the sleep area. Each curtain is retained in position with Velcro that mates to Velcro on the lockers and walls.

The privacy curtains were not used as often as intended because all three crewmen slept simultaneously, with most of the lights off in the workshop and the wardroom window shade closed. Lighting varied from all lights being turned off at night during the first two manned periods to several remaining on during the third. The frequency of using the curtain depended very much on crew preference, and soundproofing was recommended by several crewmen.

Light Baffles.- A nonreflective fabric light baffle is provided in the ceiling of each sleeping area to prevent light entrance from the forward compartment while allowing flow-through ventilation (fig. 10-25). It is supported by mating snaps and Velcro on the ceiling, walls, and lockers. The baffle in the center sleeping area has a section the size of the emergency escape exit attached with Velcro to allow breakaway emergency egress.

The crew reported that the airflow tended to collapse the fabric louvers, decreasing air circulation. They corrected this by taping triangular-shaped pieces of cardboard adjacent to the louver stiffeners. The light baffles were not used as planned, since all workshop lights were generally off and the wardroom window was covered during sleep periods.

#### 10.1.6 Food System

The food system provides the equipment and supplies necessary for the storage, preparation, service, and consumption of food. The system includes a food galley and pantry, food table, food stowage containers, food freezers and chillers, transfer and resupply, and food management. The location of the food system equipment is shown in figure 10-27.

Food Galley and Pantry.- This provides for approximately 7 days' stowage of canned food and beverages for three crewmen. The food items are stored in pullout drawers, which are color-coded red, white, and blue for individual crewman identification. Three wardroom lockers provide transfer and resupply stowage, while others restrain miscellaneous items such as utensils, wipes, food tray lids, and the specimen mass measurement device. The galley also contains a trash area for temporary stowage of six food overcans. Used food cans, lids, and beverage packets are deposited through a disposal well into the overcans. The galley and pantry with food and miscellaneous items are shown in figure 10-28. Items associated with the galley and pantry equipment, such as food, food containers, beverage containers, seasoning dispensers, the specimen mass measurement device, and food heater trays, are discussed in references 15 through 17.

The food galley and pantry system operated satisfactorily; however, several comments were made by the crewmen. The major criticisms were that the food had to be handled too many times between launch stowage and meal preparation, the pantry was not easily accessible to each crewman, and access to a specific item within the pantry trays was difficult. The crew suggested that common food items be arranged together in some sort of dispenser rather than in trays by



at the table. The thigh restraint is hinged at the table to permit selection of the desired elevation and at its midpoint for selection of the desired seating position. The thigh restraint is adjustable to conform to the crewman's thighs.

Each crewman has a personal, color-coded food tray containing four large and four small food can cavities. Three of the large food can cavities can be individually heated for preparing frozen foods. The small food can cavities restrain small food cans and beverage packets. A removable food tray lid is stowed in the galley after the food is heated.

In general, the crew commented favorably on the food table. The food preparation system worked extremely well. All table restraints worked well, except for the foot restraints. The third crew removed the table foot restraints and used the grid floor. Throughout the mission the table was used as a workbench and office area for reading and writing. Individual and brighter lighting for each crewman was recommended for these types of tasks, and restraints were recommended on the table top to hold charts, books, checklists, and so forth.

**Food Storage.**- The 11 nonrefrigerated food storage containers are common in design and construction. All four sides and the back are corrugated aluminum panels. The door is similar to the standard locker compartment doors. The container support structure is designed to configure the containers for easy accessibility to the crew (fig. 10-31). The food is vacuum packed in individual

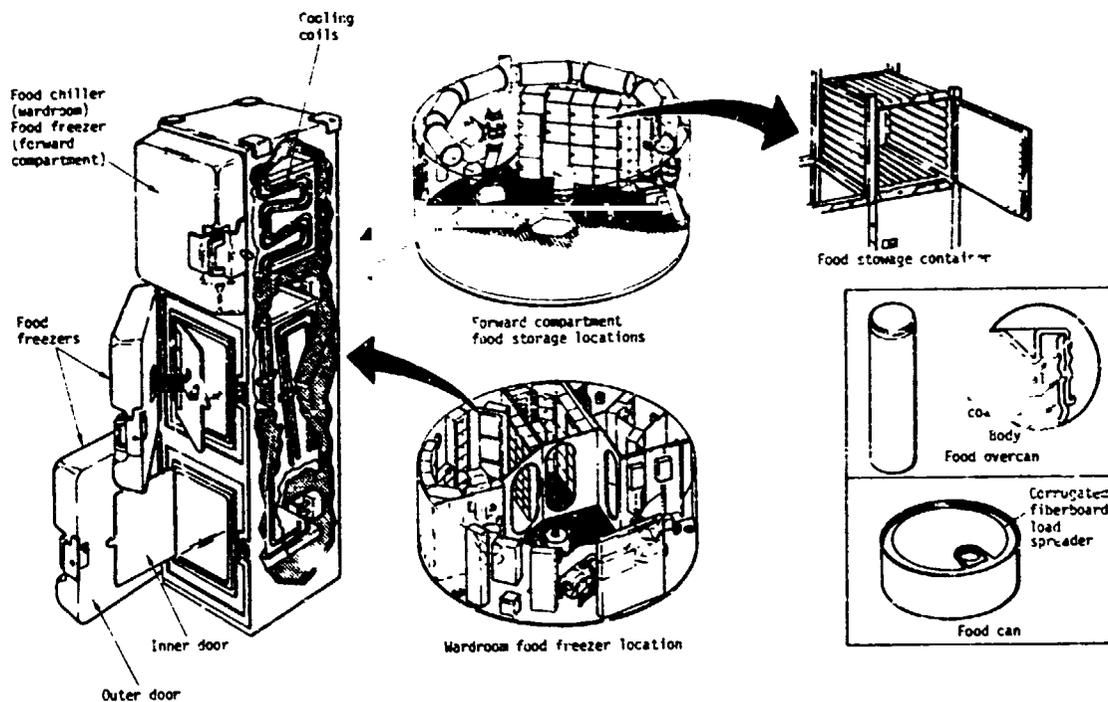


Figure 10-31.- Food storage equipment.

pull-top cans which, when opened, provide a dish from which to consume the food. Three sizes of food cans are used: large, small, and pudding. Beverages are stored, dehydrated, in accordion beverage packs to facilitate storage and drinking. The food cans and beverage packets are stored in large and small overcans, which are sealed with screw top lids to protect the contents. As the food supplies within the food storage containers are depleted, trash and transfer items,

such as pressure control unit containers and carbon dioxide absorbent shims, are removed from the command module and stored in these empty containers.

The crew reported that the flanges on the edge of the food containers were very necessary as holding devices during transfer and relocation in the food container stowage rack. The food containers were one of the largest items which the crew had to transfer and relocate, and they indicated that this was very easily accomplished.

There are five food freezers in the workshop, three located in the forward compartment and two in the wardroom. The one food chiller, located in the wardroom, is used during launch for stowing an ambient food module and in orbit for stowing leftover food items as well as experiment items. Each of the food freezers contains approximately 50 pounds of frozen food such as steaks, prime rib, and ice cream--enough for three crewmen for 28 days. The refrigeration system is designed to maintain the freezers at about  $-10^{\circ}\text{F}$ . Each freezer is accessible through a foam-filled outer door fitted with a vented gasket. All frozen food is contained in cans and overcans. Figure 10-31 shows the food freezers and chiller.

The food freezers and chiller were considered satisfactory in operation. However, the crew did comment that space utilization was poor even though the size of the compartments was relatively small, and that a means of restraining loose food items would have been desirable. There was also ice buildup between the freezer and canister doors, reducing accessibility and requiring maintenance procedures.

Food Management.-- Food transfer and resupply is part of the process required in managing the food system. The crew transfers bundles of food from the forward compartment food stowage containers every 7 days to resupply the wardroom pantry. At the beginning of each manned period, food carried in the command module is also transferred to the pantry for crew consumption.

Except for being time-consuming, food transfer and resupply was satisfactory. Food containers were easily released and transferred to their in-orbit stowage locations. Food bundles were easily transferred and items installed in the pantry drawers. The crew recommended a food handbag as a container to aid in the transfer process.

#### 10.1.7 Housekeeping

Housekeeping in the Saturn Workshop involves the collection of trash and expendable items for disposal and keeping the habitable area free of any agent that could promote bacterial growth and undesirable odors. Equipment provided for this purpose includes trash bags, disposal bags, a vacuum cleaner, and microbial control provisions. Trash is segregated into two categories: biologically active trash such as urine bags and food cans that require disposal in the waste tank to prevent bacterial growth, and biologically inactive or inert trash such as launch restraint hardware and packing material that is stowed in the plenum area or available empty lockers.

Trash Collection.-- Trash and disposal bags are cylindrical in shape and fabricated of vented Armalon. Trash bags are attached to the inside of a trash locker door and are used to collect dry and moist solids. A circular, hinged door on the locker door allows access to the bag diaphragm for insertion of trash without opening the locker door. Disposal bags and urine disposal bags are

designed to interface with standard snap patterns in useful locations throughout the laboratory. Disposal bags accept urine separators, charcoal canisters, and other large, disposable items considered as contamination sources. Urine disposal bags accept the urine collection bags. The difference between the disposal bags and the urine disposal bags is the side stitching on the latter, which decreases the bag's diameter. Plenum bags are used for stowage of trash from activation and operations that are not considered a contamination source. The trash collection provisions are illustrated in figure 10-32.

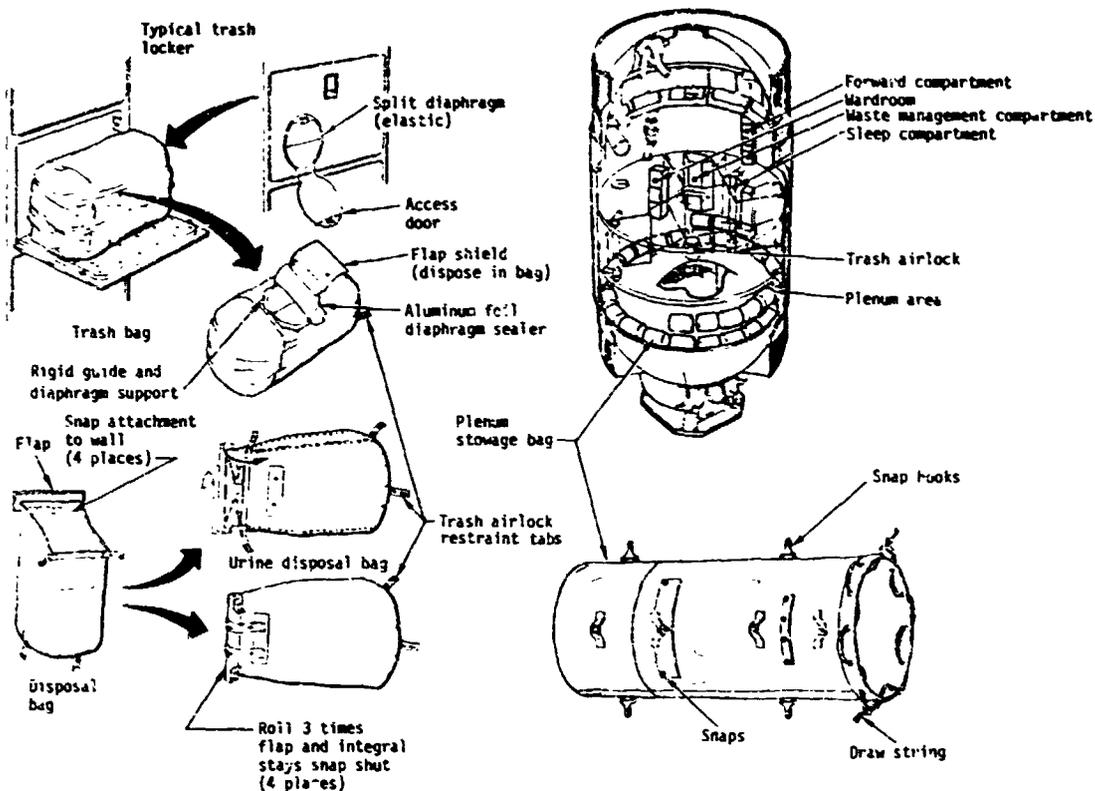


Figure 10-32.- Trash collection provisions.

No problems were encountered with trash collection; however, some difficulties experienced during bag disposal are discussed in 10.1.8. Fewer trash bags were used than planned, while more disposal bags were used. The third crew ran out of disposal bags early in the period. Table 10-VI summarizes the usage of trash collection bags. The trash bags were excellent and worked very well. The spring top on the urine disposal bags was very convenient; however, the crew felt that an easier method of sealing the bags for a low-bleed leak would have been desirable. It was considered cumbersome to wrap the flaps around and snap them to preclude the possibility of venting while in the waste tank. The plenum bags were handy to hold the dry trash, that is, empty washcloth, wine, and towel containers, when the crew ran short of disposal bags. The plenum bag was considered excellent, partially because of its additional stowage capability. The crew recommended some improvement or relocation in the trash collection provisions. The location of the trash bags in the wardroom was such that the crewmen were frequently climbing over each other from their positions at the table to obtain access. They rearranged the trash lockers for a more convenient location by removing the trash door hinge pin and swapping it with a plain locker door at a different location. The crew recommended that wet urine items, wet washcloths,

Item	Quantity onboard at launch	First manned period			Second manned period			Third manned period			Remarks
		Expected usage	Actual usage	Total remaining	Expected usage	Actual usage	Total remaining	Expected usage	Actual usage	Total remaining	
Trash bags	366	73	22	344							Includes 37 bags carried by the second crew and 18 bags carried by the third crew *As required **Estimated
Disposal bags	168	33	48	120	146	67	282	146	162	120	
Urine disposal bags	149	28	40	109	59	54	65	68	66	0	
Plenum bags	28	-	6	22	-	3	19	-	4	15	
Vacuum cleaner bags	140	24	5	135	48	10**	125	48	10**	115	

towels, and so forth be discarded in an internal locker and not a disposal bag hanging on the wall. The location and number of bags in the sleep compartment were fine but there was not much trash generated in this area.

**Vacuum Cleaner.**- The crew is provided with a vacuum cleaner along with a selection of accessories for a variety of housekeeping tasks. The vacuum cleaner contains a replaceable debris bag with a filter that prevents penetration of water or other liquid into the power unit. The vacuum cleaner, fecal-urine collector, suit-drying station, and shower all use identical blower power modules, providing interchangeability in the event of an equipment malfunction. The accessories include a brush attachment for cleaning screens, a surface tool for cleaning flat surfaces, and a crevice tool for access to tight places.

The crew reported that the vacuum cleaner worked satisfactorily; however, they all recommended that it have more suction. It was used primarily to clean the air inlet and debris screens on the mixing chamber and waste management compartment exhaust fan. The crew felt that the screens should be vacuumed about every 3 days instead of weekly as scheduled. The unit was used about 15 minutes on each occasion, and a bag change required 5 to 10 minutes. The vacuum cleaner was also used to collect hair, as shown in figure 10-33. Although designed for wet debris, it was not used for this during the mission. The usage rate of debris bags was lower than expected, with approximately 25 bags used.

**Microbial Control.**- Housekeeping provisions include biocide wipes, using Betadine (0.25 percent available iodine) as the bactericide, and wet wipes, using Zepherin chloride as the bactericide. The biocide wipes are used for general surface disinfecting as well as cleanup of major organic spills. The wet wipes are used for food utensils and food tray cleanup. A collapsible cleaning rod is used for disinfecting the metabolic analyzer exhalation hose. Additional microbial control relies on the use of general purpose tissues and utility wipes for cleanup.

The crew performed microbial control tasks generally as planned; however, they developed some interesting variations. A rag bag was established in the crew quarters for stowage of used clothing and towels that were not too dirty. These articles were used for major cleanup jobs. They also found that there was considerable cleaning capability left in the wet wipes. After cleaning their eating utensils, they used the wet wipe to progressively clean the ward-room area. The biocide wipes did a satisfactory job but were tedious to use, and the crew would have preferred a single step biocide that did not have to be washed off. A handle or holder to keep the iodine off the hands would have been preferred. They suggested an aerosol biocide and the ability to clean up with rags, which were superior to the wipes for cleaning up larger areas. The wipes and general purpose tissues ran short and recommendations were made for more of these. A preference was also voiced several times for an aromatic disinfectant rather than the aseptic-smelling biocide used.



Figure 10-33.- Use of vacuum cleaner to collect hair clippings.

The area around the food table was the most difficult to keep clean. Solid surfaces or a removable or hinged grid in the ceiling and floor in the food table area would have improved the situation and permitted cleaning of free-floating food debris. There were "definite odors" in the wardroom which emanated from the food disposal wells. These were cleaned with biocide wipes every three days. The third crew had several urine spills. The biocide wipes performed satisfactorily in handling these spills. A spill during disposal of a urine bag in the trash airlock created a major source of odor, and repeated treatment with the biocide failed to remove the odor. It is felt that the biocide did work on the accessible portion of the trash airlock; however, urine probably passed under the lower lip of the airlock into the inaccessible area, causing the foul aroma. The solution to problems like this would appear to be in the design of the trash airlock. Similar design problems were noted while cleaning the urine separator compartments, since the crewmen commented on the poor access for cleaning spills. Poor lighting in the waste management compartment made inspection of the urine drawers difficult, and there was no way to completely clean them. Smooth surfaces within the drawer would have made cleaning easier. A minor iodine discoloration was reported on objects disinfected with the biocide wipes. This was not considered significant and the crew did not report any serious objection.

Some areas were omitted from the housekeeping procedures. For instance, the food disposal area was not on the housekeeping procedure, but required frequent cleaning as it became dirty with food leftovers. Housekeeping schedules should not be rigid, that is, most areas can be cleaned on an as-required basis. The crew thought that there was too much housekeeping on a scheduled basis. Items such as the fecal collector seat should be cleaned when it is dirty and not once a week by schedule. Also screens should be cleaned when they are obviously dirty. It must be considered, however, that microbial growth is not always visible. During the third manned period, the crew found that the four liquid-cooled garments were damp and mildewed. They were cleaned with wet and biocide wipes, then dried overnight, but the mildew and odor were not completely removed, which illustrates that once microbial growth begins it may be difficult to remove. The quantity of biocide wipes provided appeared to be adequate for all housekeeping tasks, and the usage is summarized in table 10-V. No mention was made of the collapsible rod for cleaning the metabolic analyzer exhalation hose. It is assumed that the rod performed satisfactorily. The results of the environmental microbiology experiments (references 15, 16, and 17), which involve the analysis of onboard microbial swab samples, will help define changes to housekeeping philosophy.

A microbiological examination was made of a returned urine separator. Of the numerous colonies that grew in phosphate-buffered saline washes, 105 representative colonies were isolated for further study. These colonies were picked at random and represented all types of colonies seen. From these 105 isolates, it was determined that the predominant bacteria were alpha and non-hemolytic streptococcus species, micrococcus species, and bacillus species. All of these organisms are normally found in humans or as air contaminants. Two colonies proved to be staphylococcus aureus, a pathogenic organism. Six colonies were coliform organisms, also normal in humans. The predominant bacteria seemed to be the more resistant forms of bacteria normally found in humans and in the air.

#### 10.1.8 Trash Disposal

Two methods of disposing of the trash collected during the mission are provided. The nonflammable, biologically passive trash is collected in the plenum bags and stowed in the plenum area beneath the crew compartment floor. Flammable and biologically active trash is collected in trash bags, disposal bags, and urine disposal bags, and is transferred into the waste tank through the trash airlock.

Plenum Area Stowage.- The plenum bags are stowed by attaching them to cables provided in that location. The plenum bag stowage arrangement is shown in figure 10-32. Hooks for attachment are integral to the individual plenum bags. The crew encountered no problems with access to the plenum area and to individual stowage bags for retrieval of useful items. One plenum bag was filled with miscellaneous items and left in the docking adapter for retrieval in the event of a possible revisit at some future date.

Trash Airlock.- This provides a means of placing possible contamination-producing trash into the waste tank (fig. 10-34). The trash disposal volume of the waste tank is part of the liquid oxygen tank of the original S-IVB stage and is isolated from the habitation area by a common bulkhead. The interior of the tank has a network of fine-mesh screens installed to prevent solids and liquids from migrating to space. After initial launch venting, the waste tank is continuously vented to vacuum to prevent possible bacterial growth.

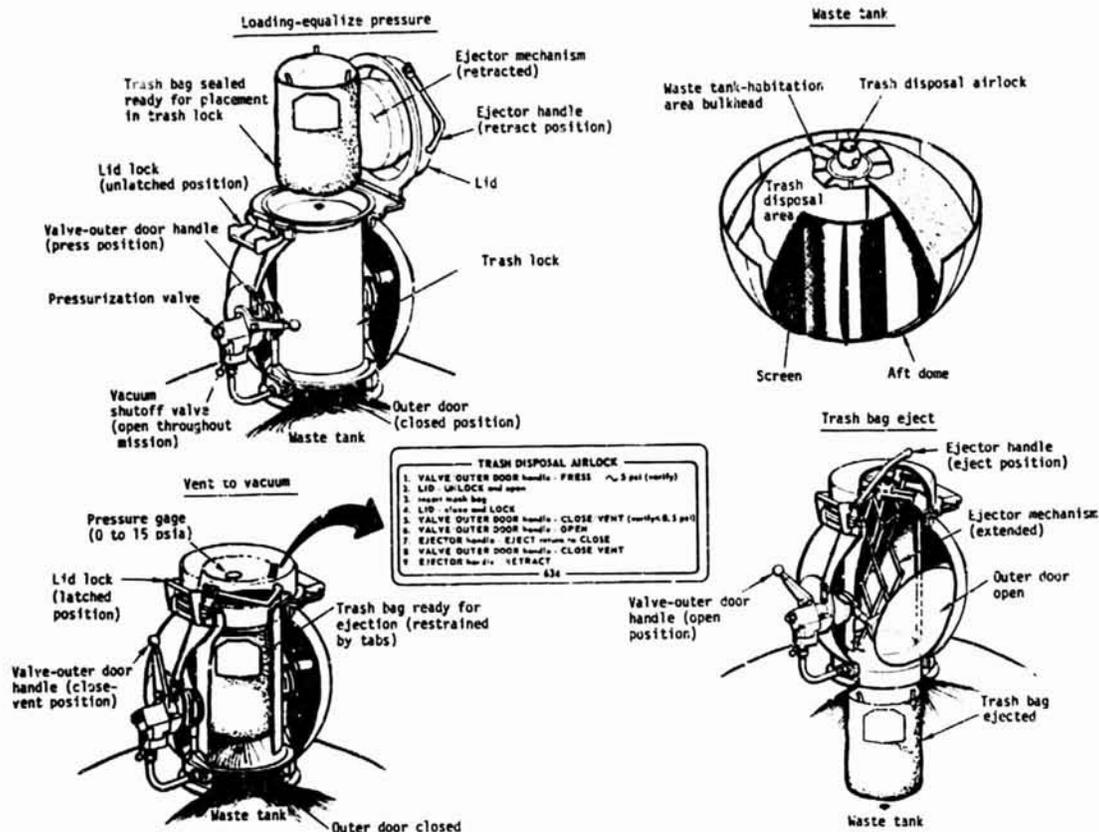


Figure 10-34.- Trash disposal airlock operation.

The trash airlock is located in the center of the common bulkhead and protrudes slightly into the experiment compartment through an opening in the crew quarters floor. The interior of the airlock contains a trash lock, approximately 14 inches in diameter and 18 inches long, which houses the trash collection bags when they are placed in the airlock. Three restraining pins are located on the upper ring of the trash lock to restrain the trash bags after insertion. The trash lock is isolated from the waste tank by a movable outer door and from the habitation area by a hinged lid. A pressure gage mounted on the lid indicates the airlock's internal pressure. To dispose of trash, the crewman rotates a valve handle to equalize pressure between the airlock and the habitation area and opens the lid. Bagged trash is placed in the trash lock and the lid closed and locked. The valve handle is again rotated to equalize airlock and waste tank pressures (vacuum). A final movement of the handle lifts and swings the outer door into the space between the trash lock cylinder and airlock body and exposes the trash bag to the waste tank. An ejector handle is operated to expel the trash from the trash lock. The ejector scissors mechanism inside the lid translates the entire length of the trash lock to ensure positive expulsion of trash. After expulsion, the extended mechanism prevents migration of trash back into the trash lock until the outer door is closed by rotating the valve handle. After the door is closed the vent valve is left in the vent position to maintain a vacuum in the trash airlock to inhibit microbial growth inside the airlock body. Figure 10-34 shows trash airlock operation. The trash airlock has a projected use of 750 cycles based on 5 operations per day. Ground testing has certified the unit for 3000 cycles. In the event that the trash airlock becomes

inoperative, a contingency trash management plan provides for segregating, processing, and stowing the trash.

The total trash airlock usage by all three crews was approximately 660 cycles, or an average of less than 4 times a day. On occasion the crew encountered some difficulties in trash disposal. During disposal of a trash bag filled with urine collection and transfer assemblies, the first crew found that the ejection force required was extremely high. This was apparently due to a high air content in the urine, which allowed the bags to expand while in the airlock. The crew felt that closer control of the amount of material placed in the bag, in addition to wrapping the bag with tape, would prevent this. The outer door also jammed in the open position when a waste disposal bag containing a molecular sieve charcoal canister and four extravehicular activity gloves lodged in the trash lock cylinder while being dumped. The crew solved the problem by cycling the ejector mechanism. During subsequent investigations on the ground, it was found that a urine separator with its motor could jam the trash airlock. It was therefore recommended that the crew not attempt to dispose of the urine separators through the airlock, but stow them in an empty experiment sample array stowage container. Air in this container was then evacuated to prevent possible bacterial growth.

Early in the second manned period, the ground noted a slow decrease in habitation area pressure, with a leakage rate of 6 lb/hr. The crew was awakened 6 hours later by the sound of makeup gas being added to the atmosphere. They were instructed to check the position of the trash airlock valve handle and found that it had been bumped into a position midway between the pressurize and vent positions. This position allowed leakage of cabin air into the waste tank. The crew then began restraining the valve handle in the pressurize position with a strap, and no further instances of leakage occurred. On some occasions, excessive crew effort was required to compress the lid O-ring seal and disengage the interlock before the door handle could be moved (fig. 10-35). The second crew was told that they could use one of the spare onboard seals if they wanted to; however, they chose to continue with the original seal. On Day 116, the crew reported that the interlock linkage between the lid lock and the outer door handle was bent. This could have occurred if the lid latch was operated while the outer door handle was in the wrong position. The bent rod did not affect the operation of the airlock. Subsequent video tapes showed successful one-man operation after the report of a bent interlock linkage.

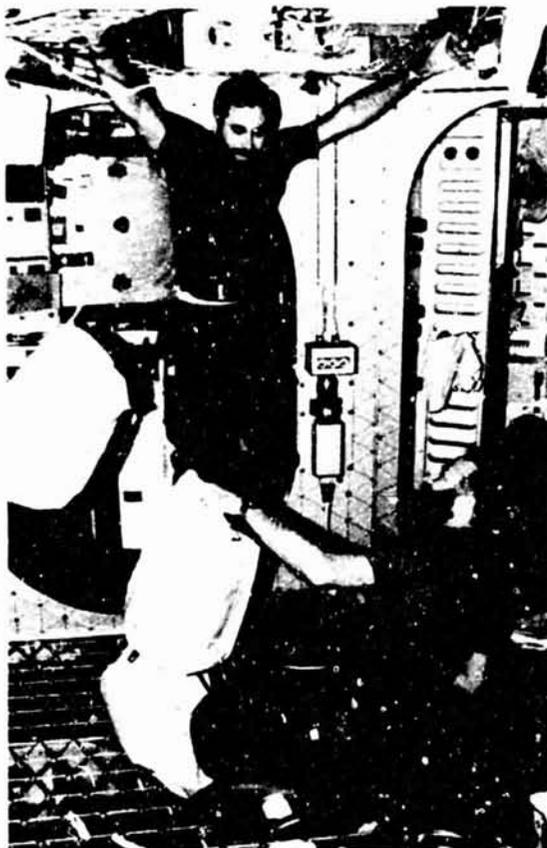


Figure 10-35.- Opening the trash airlock.

About midway in the third manned period, for no apparent reason, the crew

found it difficult to dump full urine disposal bags. Reducing the number of urine bags per disposal bag solved the problem. On one occasion the crew opened the valves on the urine bags, which resulted in a significant urine spill inside the trash lock. Also toward the end of the mission, again for no apparent reason, it became necessary to use two men to operate the lock, one standing on it to force the lid down and the other to latch it. It was recommended that the crew deactivate the interlock by taping the linkage, thus reducing the seal compression and closing force required. The crew did not indicate whether or not this was done.

Other than the incidents discussed above, the operation of the trash airlock was acceptable. To reduce the possibility of jamming, continuing care was exercised in avoiding overfilled trash bags, urine disposal bags, and large items with protrusions. No items were reported to have been dumped through the trash airlock without being placed in some type of bag. The crew expressed their feeling of dependence on the trash airlock and their concern about the situation that would result from a permanent malfunction. They also occasionally criticized the amount of time needed for trash disposal and termed the operation a "nuisance." A detent should have been on the valve handle to positively maintain the handle in position to prevent atmosphere loss, and the force required for the lid latching operation should have been reduced. Since there were no malfunctions which precluded use of the trash airlock, the contingency plan for trash disposal was never required.

The available disposal volume in the waste tank for ejected biologically active trash was 2233 ft<sup>3</sup>. Table 10-VII summarizes waste tank usage during the mission, assuming the bags were maintained at their extended volume by the

Table 10-VII.- Waste Tank Usage

Bag	Volume (ft <sup>3</sup> )	Available bags		Total used	
		Number	Volume (ft <sup>3</sup> )	Number	Volume (ft <sup>3</sup> )
Trash Disposal	1.0840	566	397	246	267
Urine disposal	1.41076	168	237	168	237
Vacuum cleaner	1.02909	204	229	204	229
	0.01236	140	2	25	0.3
Totals		878	865	643	733.3
Use of space			19%		33%

sublimation of the ice resulting from the moisture in their contents. Some biologically active trash was disposed of in plenum bags (4.5 ft<sup>3</sup>). Of the 13 used, only 9 are known to have been stowed in the plenum area. Despite the problems of getting the trash into the tank and the possibility of external contamination, the waste tank disposal concept was satisfactory.

#### 10.1.9 Debris Control

The primary active means of debris control in the Saturn Workshop is the use of airflow as a gravity substitute. This is augmented by different types of closeouts installed around lockers, equipment, and other structures to prevent loose debris from collecting in inaccessible areas. Special tools are provided to assist in retrieving loose items that find their way into tight spaces. In the workshop, air is circulated from a plenum at the aft end of the vehicle through diffusers to a mixing chamber located in the forward dome. The air is returned to the plenum area by a fan and duct arrangement. This configuration provides air velocities ranging from 20 to 45 ft/min, with air velocity through the screens of approximately 283 ft/min. The screens are cleaned periodically with the vacuum cleaner. Similar arrangements exist in the airlock and docking adapter.

Upon initial entry, the first crew found the laboratory as "clean as a whistle," and only a few small loose hardware items were found. During the

mission, loose debris eventually migrated to the screens where the airflow was greatest, that is, the docking adapter ventilation fan screens and the workshop heat exchanger and mixing chamber screens. The debris that collected on these screens was conveniently removed using the vacuum cleaner. The debris closures served their purpose with no problems.

#### 10.1.10 Mobility-Stability Aids

Mobility-stability aids are provided throughout the Saturn Workshop to assist the crew in translating to and from work stations and for restraining themselves while performing various mission tasks. Handrails, handholds, the triangular grid, and body restraints for the feet, thighs, and lower legs are provided as fixed mobility-stability aids for performing specific tasks. Portable restraints are provided for use at a variety of work stations. Many other items of equipment located throughout the interior serve as mobility-stability aids, although that is not their primary function.

Fixed Aids.— Handrails and handholds shown in figure 10-36 are situated in the laboratory to assist the crewman in translating or maintaining temporary body stability while performing one-handed tasks. During the mission, it became obvious that hand-over-hand translation inside a large volume is not required as a means of locomotion. The handrails were used primarily as a springboard for body movement and as a brake or pivot for reorientation. Since the arms are the major means for crewmen to propel themselves in zero gravity, the crew felt that there was a need for more handrails and handholds in high traffic areas. These aids should be as close as possible to equipment so that points where torques and opposing forces are applied are close together. The crew also indicated that many of the handrails located at work stations for stability should have been foot restraints.

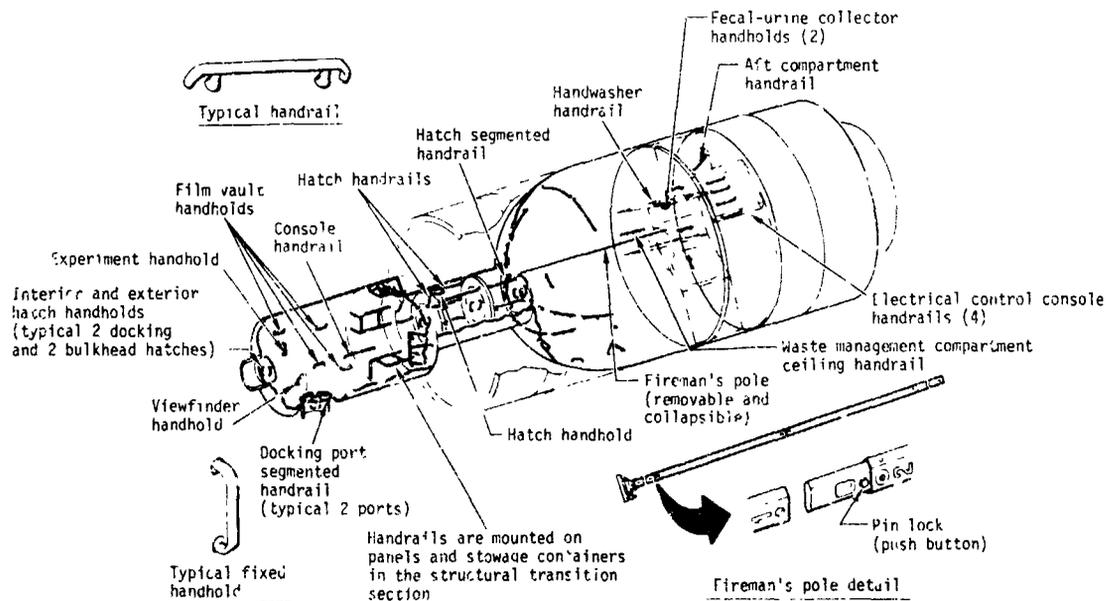


Figure 10-36.— Fixed handrails and handholds.

Waste management compartment foot restraints enable the crewmen, while barefooted, in stockings, or in soft boots, to use the urine collector and handwasher, and to perform various hygiene and maintenance tasks with both hands

free. The restraints are mounted on the compartment floor and are adjustable to various foot sizes (fig. 10-37). The two locations of the waste management compartment foot restraints were judged to be unsatisfactory. The Velcro strap did not hold well; it was too stiff and too short and could not be used satisfactorily with the triangle shoes. A new strap was flown with the second crew, but did not perform as expected. It was too short for use with triangle shoes and too long for use without triangle shoes, and was frequently caught when crewmen opened the urine drawers.

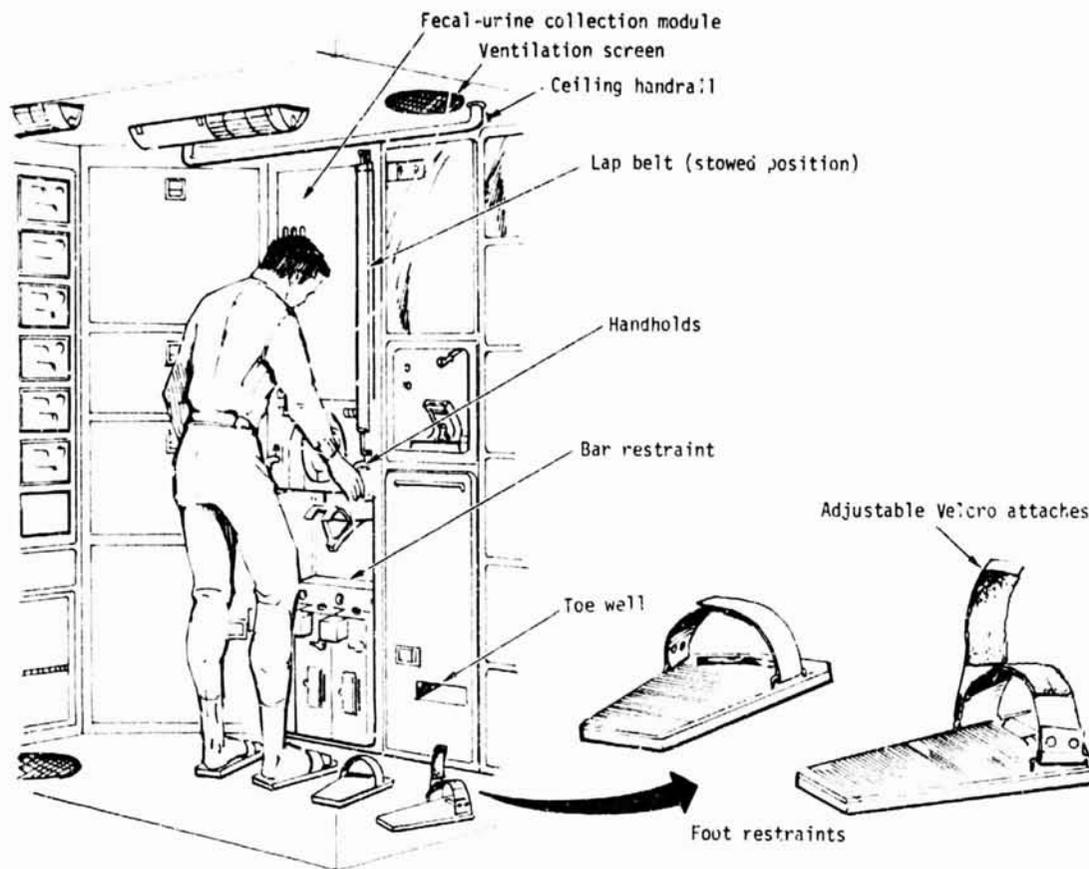


Figure 10-37.- Waste management compartment restraints.

Fecal collector restraints provided at the fecal-urine collection module consist of a lap belt to secure the crewman against the contour seat, handholds, and a bar restraint which allows the crewman to firmly restrain his lower extremities. In general, the crew felt that the fecal collector restraints allowed them to accomplish fecal collection satisfactorily. They all agreed that one must use both the handholds and bar restraint. Some felt that the lap belt was an absolute necessity while others said that it was not required. All crewmen commented, however, that in one way or another the equipment served its intended purpose. The major objection was the lack of adequate restraints when performing the various waste management and medical experiment tasks.

A toe well, located in the door below the handwasher, is used for foot restraint while performing various hygiene activities, such as cutting hair, so that the crewman can be close to the ceiling airflow debris filters. The crew made no specific comments pertaining to the toe well.

A "fireman's pole" is provided in the workshop forward compartment to assist the crewman in translating from the hatch area to the forward floor. The crew found this item useful and at times preferred it over the adjustable tether strap. Because of the rigidity of the pole, they could grab it and change direction easily and more accurately than with a flexible strap. The objections were that it was possible to cut one's hands on the roll pins used for attachment, and that the pole also tended to rattle in its fixture when impacted, which disturbed crewmen attempting to sleep.

The floor and ceiling of the crew quarters are equilateral triangular grid cutouts, machined from aluminum plate (fig. 10-38). They provide both a

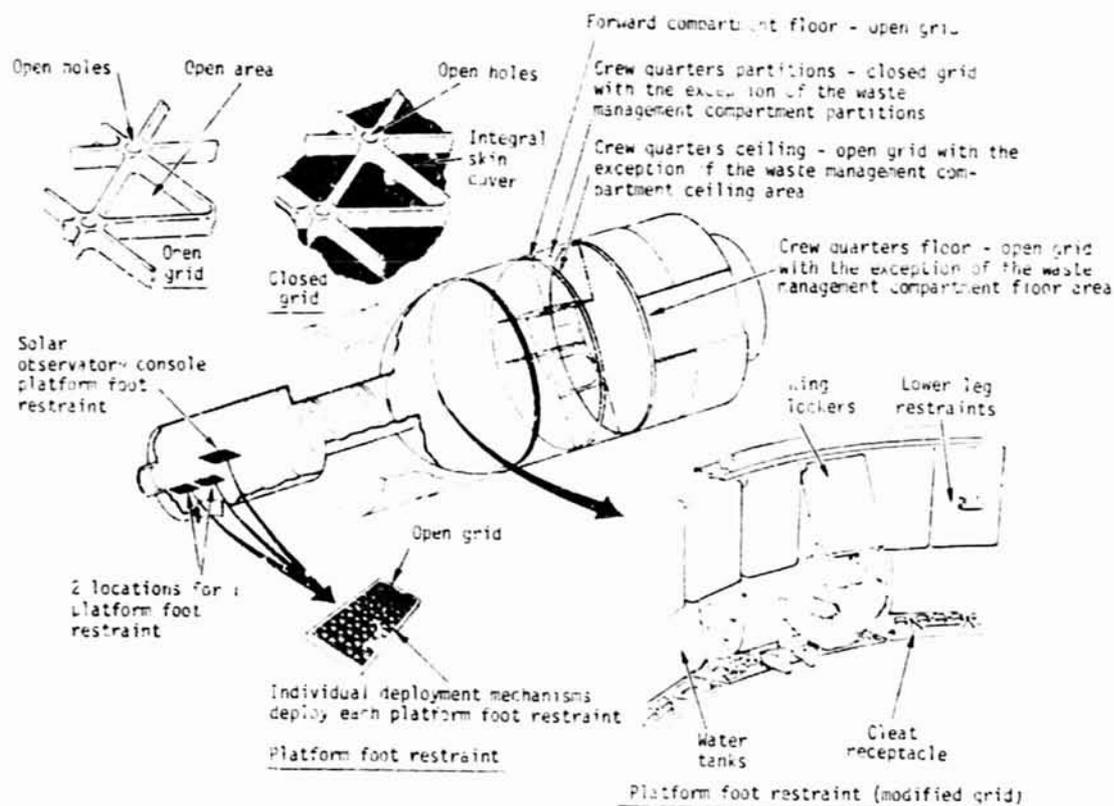


Figure 10-38.- Grid type foot restraints.

handhold for the crew and a locking device for the triangle shoe (fig. 10-39). The grid concept was carried over from the wet workshop concept in which it was necessary to allow liquid hydrogen to flow through the compartments during powered flight. The same type of grid is used for restraint purposes at other work stations. The usefulness of the floor and ceiling grid for mobility and restraint received favorable comments from all crewmen. The two most common objections concerned the lack of grid in some areas and blockage of the grid by installed equipment or supporting structure. The lack of grid in the waste management compartment was particularly noted. The main floor beams and inter-costals were so close to the grid that the triangle shoes could not be used around them. One minor deficiency was that food crumbs, debris, and spills migrated into spaces between the grid facings. A slightly larger triangle cut-out would have allowed easier hand access for cleaning and debris removal.

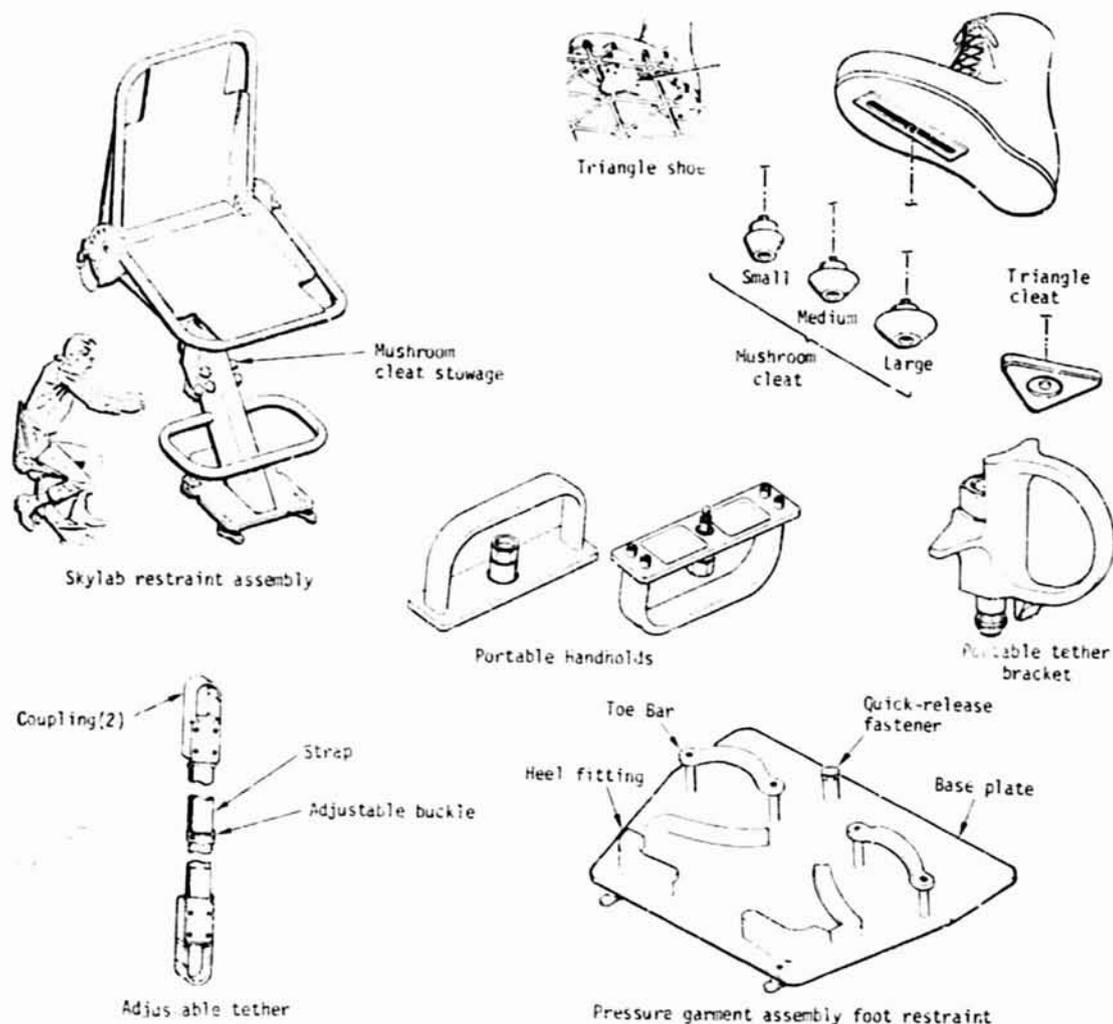


Figure 10-39.- Portable restraints.

Foot restraint platforms are installed beneath the water tanks for use with the triangle shoes. They assist in restraining and maintaining body orientation while applying any necessary forces with both hands to remove or replace equipment in the forward dome ring lockers. The crewmen employed the water tank foot restraints in various ways. One engaged one foot in the triangular grid, while others engaged both feet or stabilized with the hands only. While connecting water hoses and the condensate tank hoses, one crewman lay parallel to the platform and grasped the tank between his knees to allow freedom for his hands. All three crews assessed the restraints as very good and necessary for most tasks performed in that area.

Lower leg restraints are located on two ring lockers to assist in translating, positioning, and installing the condensate holding tank in its stowage location on the forward dome. The first crew indicated that the lower leg restraints worked well, especially for stabilizing and positioning large masses. Neither the second nor third crew reported using this device.

Crew restraint for operations at the solar observatory control and display console is provided by a triangular grid foot restraint platform that may be

adjusted to three positions relative to the console or folded into a stowage position. The platform is designed for use with the triangle shoes (fig. 10-2) and the chair-type restraint assembly (fig. 10-39). The Skylab restraint assembly provides the crew with a chair-type body restraint for working at the solar observatory control and display console. The chair is designed for attachment anywhere along the foot restraint platform. It has 11 adjustments in height above the platform and 9 adjustments in backrest tilt from the seat of the restraint. The seat has five positions of tilt with respect to the platform. A tubular footrail can be employed as a foot reaction point. The first crew used the chair continuously and found it very useful. They felt that the chair prevented them from becoming tired while operating the console. The second and third crews thought that the chair merely restricted their reach and therefore was of no use. The second and third crews did not report any fatigue while remaining in an upright position at the console. The foot restraint platform, used throughout the mission in the lowest position, permitted the crewmen an envelope completely adequate to perform all solar observation operational tasks, and seemed to offer the best operational stability aid.

A movable, triangular grid platform, similar to the solar observatory platform, is used for restraint while a crewman is working at either the materials processing facility or Earth observation experiment workstations. The platform worked exceptionally well for the Earth observation experiments. The triangular grid was constantly mentioned as a good type of restraint. The crewmen agreed on the need for a similar restraint at the nearby viewfinder tracking system station, and evidently would desire this type of restraint at all work stations. The concept of using a single foot restraint platform at different locations should be discouraged, especially when it must be moved many times during the mission.

Portable Aids.- These are foot restraints, handholds, tethers, and shoes that afford the crewmen mobility and stability in operations throughout the laboratory (fig. 10-39). Three pressure garment assembly foot restraints attach to the forward compartment grid floor to restrain the pressure suit boots for suit drying, or to generally restrain a pressure-suited crewman. The portable foot restraints worked successfully for suit donning and doffing as well as suit drying. One of the restraints, modified for use during extravehicular activities by removing two heel-retaining pins and the quick-release fastener, was found to work very well by the first crew. One crewman, however, had difficulty removing his left foot from the restraint during an extravehicular activity. The second, third, and backup crews' pressure suits were fit checked in a restraint to ensure that the problem did not recur.

Six portable handholds provide the crewman with handhold restraints wherever open grid is available. They can be used with the gloved or bare hand. A button-operated, quick-release fastener attaches or detaches the handhold from the circular hole in the grid. The first crew used the portable handholds when riding the bicycle ergometer. They had trouble with one fastener, and in the process of trying to replace it with one from another handle, the second fastener was destroyed. The tongs that engage the grid apparently were bent. The second crew used the handholds for stability while performing the crew vehicle disturbances experiment. Neither the second nor third crews reported any problems. The crewmen concluded that the portable handhold was not required as a restraining device.

Nine portable tether brackets are used as restraining points for straps and equipment restraints wherever open grid is available. The brackets attach to the grid hole with a button-operated, quick-release fastener and provide smooth, rounded attach points (fig. 10-39). The only reported use of the portable tether brackets occurred during the first manned period, when the crew used them to rig ropes with handles for better restraint while pedalling the bicycle ergometer.

Two adjustable, flexible tethers are provided mainly as a supplement to the fireman's pole. One is attached between the workshop hatch bracket and the forward compartment floor as a translation aid from the dome area to the aft compartment. The other tether is attached to the forward compartment wall handholds, strung through the condensate tank handholds, and attached to a dome handhold. This tether is provided as a means of guiding and stabilizing the condensate tank while translating the tank from its launch location to its in-orbit stowage location. The first crew used the tethers for initial activation of the workshop, but removed them later. The second and third crew used a tether for evaluation but removed it and used no translation aid in the area. One was broken sometime in the first manned period, but was repaired with tape. The tether was judged not necessary or required except possibly during the early part of the mission.

Triangle shoes are provided each of the crewmen to enable them to lock their feet into open floor and ceiling grids, foot restraint platforms, ergometer foot pedals, and the food table restraints. They provide the crew a means for stability, maintaining body orientation, and applying forces with both hands free. The laced, high-topped shoes are fitted with an indexing, triangular grid cleat. A slight rotation in the grid engages and locks the cleat. In addition to the indexing cleat, three sizes of conical "mushroom" cleats are also provided for attaching to the shoes to provide temporary foot restraint for short-term tasks. The mushroom cleats may be interchanged with the indexing cleat by removing the attaching wing nut. They fit into the grid pattern, but do not lock, and require that a constant force be applied to hold them in place at the apex of the triangle. Crew preference for the type of footwear as well as the configuration of the triangle shoes varied. One of the first crewmen wore his triangle shoes every morning, with a large mushroom cleat on his right foot and the triangular cleat on his left foot. Another preferred the soft boots to the triangle shoes and wore them at every opportunity. All of the crewmen used the triangular cleats on the ergometer. The second and third crews used the shoes with triangular cleats most of the time. The toes of the shoes abraded and wore out from the crewmen's dragging their toes over surfaces to slow down while translating. The second crew took along toe caps which prevented toe wear, but which did not help other parts of the shoe. The third crew carried extra shoe tops. In spite of problems, whether real or caused by unusual use, the triangle shoes were found to be necessary. The crew thought they were the most useful, versatile restraint device available. The mushroom cleats, however, would become caught in the grid on occasion, and using the ergometer required changing from mushroom to triangle cleats.

Translation within the vehicle was easily accomplished by pushing off and floating to a particular location. Locomotion modes varied according to the areas being traversed. Movement in open spaces, such as the workshop dome area, was accomplished mostly headfirst along the principal body axis. This was also the case in the smaller compartments where movement was restricted. Since the workshop gravity orientation provided the crewman with a visual reference system,

the crew moved about erect with respect to the arrangement, as one would do in any Earth-based laboratory.

The crew experienced no problems with mobility, and they experienced no significant motion sickness and very little disorientation as a result of translation activity. The crew did not injure themselves by impacting stationary objects when translating, as such objects had rounded corners and edges wherever possible. In moving around and stabilizing themselves, the crew frequently used their toes. They dragged their feet over the grid, stuck their toes into the grid, and hooked their toes under things. The crew consensus was that a good foot restraint was superior for most tasks. Points along a crewman's translation path where directional changes are necessary or where tunnel entry is required must have mobility aids (fig. 10-40). A buffer ring of soft material is required at hatches to protect the lower body extremities during translation through the hatch.



Figure 10-40.- Tunnel entry.

Handling and translating large objects presented no problems. All large portable items should have handles or handholds on them to enable crewmen to guide them while moving them. Long, thin items are easy to handle if one can see the end of the item being maneuvered. Moving, slowing down, and stopping large or heavy objects is no problem if the crewman has something with which to restrain himself. A restraint like the fireman's pole is required for midcourse correction during translation and is helpful for fast translation. Handling many small items, however, was difficult, and uniquely designed containers should be provided.

## 10.1.11 Stowage

A variety of stowage devices are provided in the Saturn Workshop for launch and in-orbit stowage. These include containers, compartments, vaults, and equipment restraints. Individual stowage locations are assigned numbers that aid crewmen in rapidly identifying the general area within which an item is stowed. The equipment stowage provision locations are shown in figure 10-41. Access to the various size stowage lockers is provided by a number of different fastener types.

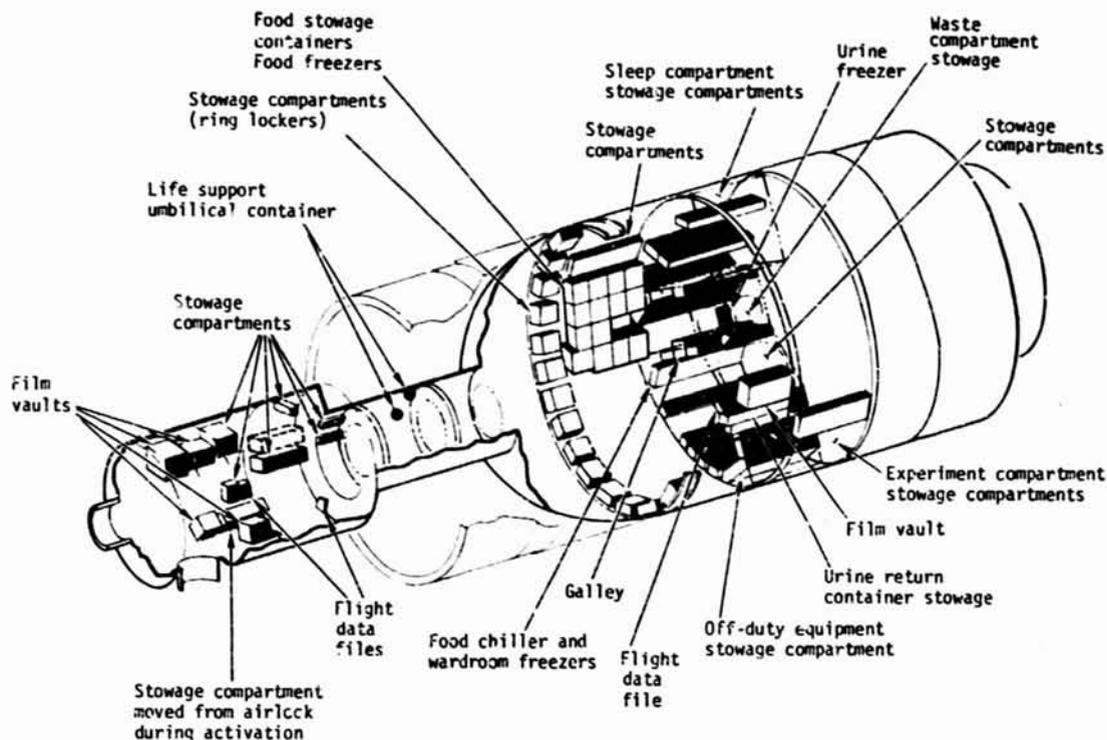


Figure 10-41.- Equipment stowage provisions.

**Stowage Containers.**- These are designed to house various items of loose equipment. Some of the stowage containers in the workshop are refrigerated for stowing food, urine, and medical specimens. The containers called standard compartments, which are the most numerous in the workshop, have identical internal dimensions and door configuration. These are used for launch stowage, in-orbit stowage, dispensers, and trash containers. With the exception of the ring lockers, the workshop stowage compartment interiors have holes on the top and bottom into which adjustable straps or other kinds of restraint hardware are attached for launch or in-orbit restraint of the stowed items. Items stowed in the ring lockers are custom-mounted and are restrained with permanent straps or bolts. Four film vaults in the docking adapter and one in the workshop are designed with varying wall thicknesses to provide radiation protection according to the film's sensitivity and the length of storage required. The various sizes and shapes of the airlock and docking adapter stowage containers provide for custom-fitted stowage of experiment hardware and operational equipment for support of Saturn Workshop systems. The stowage containers are arranged to stow equipment in primary usage areas and in some instances to group together similar items such as spares, resupply items, or photographic equipment. Figure 10-42 illustrates various typical stowage configurations.

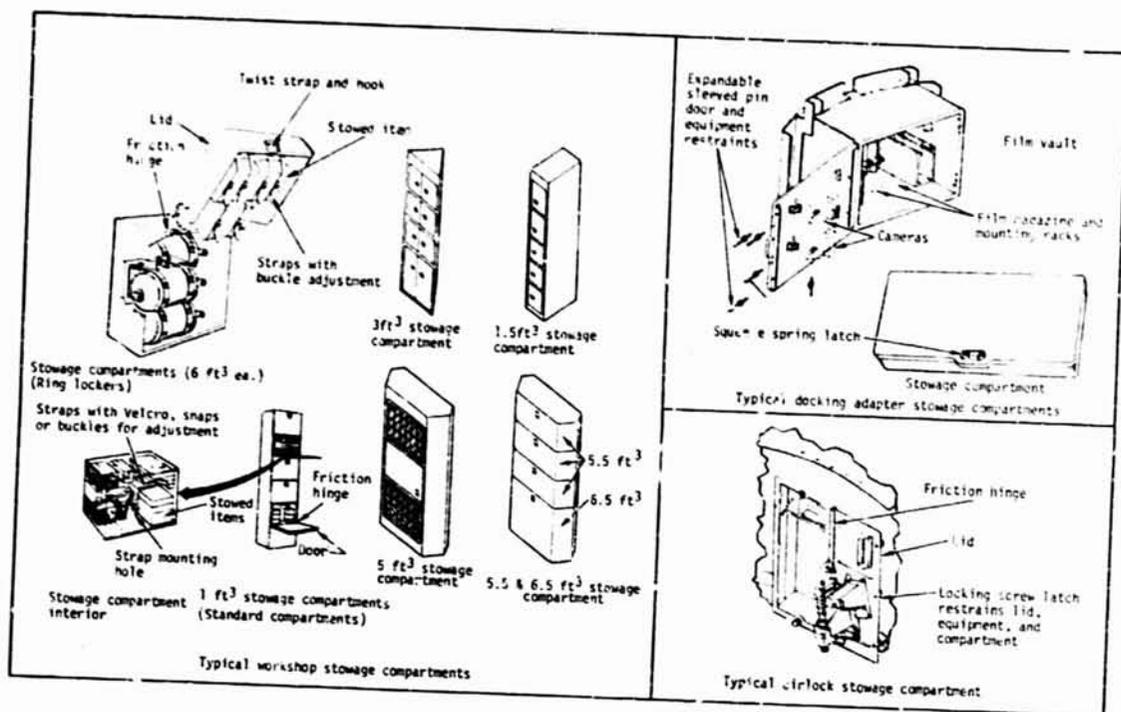


Figure 10-42.- Stowage compartments.

Except for problems with the workshop film vault and a few latches, the stowage containers all functioned as planned. The door openings provided adequate access to contained items. The doors remained closed during the launch phase and were easy to operate with none of the latches jamming. Several of the workshop standard compartment door latches failed or did not provide a positive latch. The crewmen occasionally snagged their clothes on the workshop tissue access doors and trash door because the door springs did not hold the doors completely closed. Some of the crewmen felt that the compartment doors should have an elastic restraint on the exterior surface to temporarily secure loose items. They improvised by using the bungee restraints. The workshop film vault design made it difficult to use. Hinging the doors in the middle prevented both doors being open at one time and complicated the transfer of items from one side to the other. Items in the vault drawers tended to float out, restricting the drawers from closing. Lids on the drawers would have prevented this. The third crew also reported that the film vault door latches did not function properly.

In most instances the arrangement of containers in the Saturn Workshop proved satisfactory. Comments from the crew indicated that they would have liked the items stowed in a more logical order. The trash bags, for instance, should be stowed in one central location, and tools used together should be stowed in the same location.

**Equipment Restraints.**- Two general categories of restraints are provided. Launch restraints are designed to protect the equipment during powered flight and allow removal for use in orbit. In-orbit restraints are provided for use at various locations during the mission. They include 12-inch short straps, 26-inch long straps, 73-inch equipment restraint straps of a flexible webbing, 11-inch coil-spring bungees, and universal mounts. The straps attach with snaps or Velcro, the bungees attach with hooks or snaps, and the universal

mounts lock into the triangular grid or clamp onto a handrail (fig. 5-14). There is also a supply of self-adhesive snaps and Velcro in the repair kit for use wherever desired.

There was no malfunction of launch restraints. These were used in orbit as anticipated, and the in-orbit restraints were used extensively. The first crew reported that film cassettes in the workshop film vault kept moving to the rear of the drawer. A restraining tab was apparently not locking them in place. Similar restraints in other film drawers apparently worked satisfactorily. The second crew found camera equipment loose in one of the drawers. Stowage of this equipment had not been anticipated before launch and no restraints were provided. The restraint straps in the workshop containers were somewhat difficult to use because they were stiff and rough, and in some cases the buckles settled into hard-to-reach places when the locker was partially empty. In general, the sponge rubber type restraints allowed small items to float free. The short straps would have been more useful had they been a few inches longer. The crew felt that more in-orbit stowage facilities should be provided near places where equipment would be used. As an example, more permanent stowage provisions for photographic equipment near the wardroom window would be desirable to facilitate photographic tasks at that location. More Velcro and other temporary stowage facilities throughout the laboratory were recommended. Two stowage provisions that the crew disliked were bags inside of bags and little cubicles for items like flashlights. Launch padding type restraints are not needed for in-orbit stowage.

Placards and Labels.- These provide location information for stowed items and procedural information for equipment operation. Each stowage provision is fitted with a stowage label that contains the assigned stowage number, the items stowed, and their quantities. An alphabetical listing of stowed items and the crew checklists refer to the stowage number to aid the crew in locating these items. Marking pens are used by the crewman to write on a label or container surface to track the status of the contents or to reidentify the container. Stowage location numbers differ from panel numbers. In most cases the stowage location numbers define different physical locations within the laboratory.

The crew commented that the location of labels on the tool kits prevented easy reading. A more logical numbering system in the forward compartment, to separate wall and floor stowage, would have been helpful. Time was wasted in searching for these stowage locations. In areas where many small components with similar names or shapes are used, the placards should include a picture or sketch of each item. The first crew experienced some confusion because the trash airlock has both a stowage location number and a panel designation for two distinct purposes.

Fasteners.- Nineteen different fasteners are frequently operated by the crew. For comparison, these are divided into three categories by their specifically assigned function and frequency of use. For example, some of the fasteners are designed to withstand the launch environment, and others are used only in orbit. Most of the different types of fasteners onboard were used extensively by one or more crewmen during each manned period. Several of the lifthandle latches on the workshop standard compartments and the locking screw latch captive retainers were broken. The pushbutton latch, used on the food tray lid, occasionally slipped through the latching hole in the mating surface and required prying to release it. Latching was not positive and the latch released when bumped.

The results of the ranking of the 19 fasteners by the first and second crews are summarized in table 10-VIII. The fasteners were evaluated on a subjective 1 to 10 scale with 10 being the highest rating. They are listed in ranking order within the three usage categories. Two factors appear to account

Table 10-VIII.- Subjective Evaluation of Fasteners

In-orbit use only		Launch and in-orbit use			
		Frequently engaged or disengaged		Infrequently engaged or disengaged	
Fastener	Mean rating	Fastener	Mean rating	Fastener	Mean rating
1. Magnetic latch	9.83	1. Springed ramp latch	8.75	1. Rifle bolt latch	6.00
2. Handle and trigger latch	8.50	2. Lift handle latch	8.50	2. Thumb screw and dog latch	5.40
3. Squeeze spring latch	6.00	3. Ball locking pin	7.00	3. T-bar latch	5.34
4. Pushbutton latch	2.00	4. Suitcase latch	6.16	4. Springed slot screw	5.20
		5. Locking screw latch	4.75	5. Knob handle screw	5.00
		6. Restraint straps	4.33	6. Expandable sleeved pin	4.00
		7. Twist strap and hook	3.50	7. Locking collet pin	3.67
				8. Twist lock	3.00

for most of the differences in ratings: simplicity of design and operation, and sensitivity to minor misalignment between mating parts. The highest rated fasteners are simple, straight-forward designs that can tolerate minor changes in alignment. The most consistent criticism of the low-rated fasteners is that the alignment of mating parts is too critical. The magnetic latch, which received the most favorable rating, is not suitable as a launch restraint. A useful combination might be a magnetic latch and a separate, positive launch restraint, which could be held open during orbital operations. In several cases, minor design modifications might have resulted in significantly higher ratings. For example, the suitcase type latches tended to flop and sometimes reengage after release. Built-in friction at the hinge point might eliminate this objection. Other criticisms concerned fastener usage rather than faults with the fasteners themselves. For example, alignment-critical fasteners might be acceptable for use on rigid mating pieces but not on flexible sheet metal covers.

#### 10.1.12 Illumination

The Saturn Workshop is artificially illuminated by fixed and portable lights. The fixed illumination system provides interior illumination for initial entry, normal and emergency crew activities, and experiment operations. Portable lights provide supplemental illumination for crew use and for television and photographic requirements. During the daylight part of the orbits, additional illumination can be obtained by opening window covers.

**Area Illumination.-** This consists of 50 fluorescent floodlights, four 20-watt incandescent fixtures, and twenty 10-watt incandescent handrail lights. Figure 10-43 shows the quantities, types, and locations of these lighting fixtures. Most of the floodlights are located in the workshop, as that is the largest area and the distances from the light sources to the work areas are the greatest there. The fluorescent floodlights give maximum illumination with minimum power consumption. Each floodlight assembly includes a three-position switch to provide high (12.5 watts) or low (9 watts) intensity light, or to turn it off.

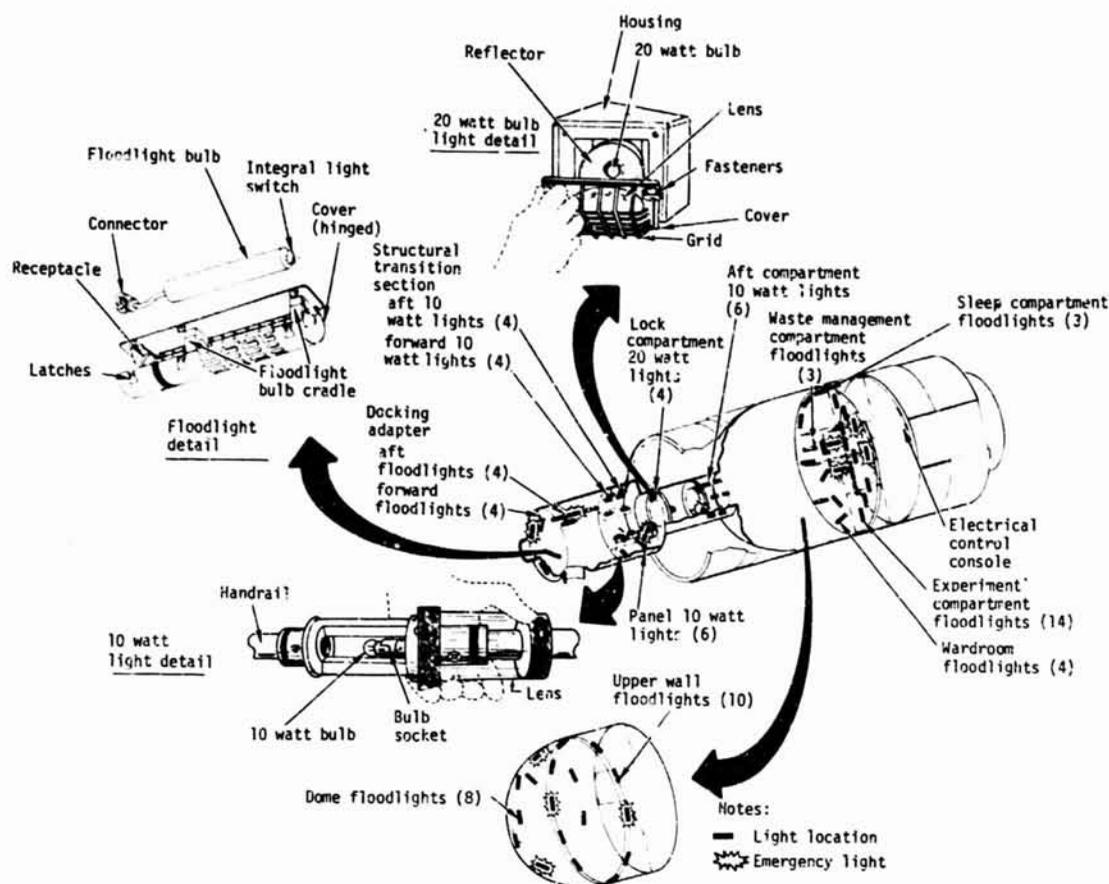


Figure 10-43.- Saturn Workshop internal lighting.

All four of the 20-watt lights are in the lock compartment. Each replaceable bulb is mounted in a reflector lamp housing and covered by a translucent lens and protective grid (fig. 10-3). The control switch for the 20-watt lights turns on either two or four lights, providing two levels of illumination and aiding in power management. The twenty 10-watt light fixtures are mounted in the handrails. Fourteen of these are used in the structural transition section and are controlled by dimmers to provide a continuously variable level of illumination. The other six are in the aft compartment of the airlock and are controlled by a two-level switch to turn on either three or six lights as required. The bulb is replaceable and is enclosed in a transparent cylinder.

The general illumination level is 5 foot-candles at all habitable areas in the airlock and at the solar observatory console and materials processing station in the docking adapter. General illumination in the docking adapter is 3.5 foot-candles when measured along the longitudinal axis. Illumination levels for the habitable areas of the workshop are listed in table 10-IX.

The power shortage experienced during the initial 14 days of the first manned period required lighting to be at the absolute minimum. During the second and third manned periods, light use was restricted during periods of high beta angles, when the periods of time in sunlight are longest, to reduce the heat input in the workshop area. The crew reported that they usually worked with all the floodlights on high power and turned all of them off during the sleep periods. Some of the 10-watt lights were left on for night lights.

Table 10-IX.- Illumination Levels in Working Areas

Area	Foot-candles (minimum)
Sleep compartment	4.5
Wardroom	5.0 at an average distance of 3 feet from the ceiling
Waste management compartment	9.0
Experiment compartment	5.5
Forward compartment	1.0 at an average distance of 3 feet from the light source

There were no problems associated with the lighting other than a switch malfunction and a slightly greater than anticipated lamp replacement schedule. The switch problem occurred when two floodlights in the docking adapter went off. It was found that a switch on the control panel was intermittent. The switch was cycled until the lights came on, and was then taped in this position. These two lights were then controlled by the switch on the light assembly. Most of the 10-watt bulbs in the airlock were changed out by the second and third crews, because of the decreasing light level due to metallic plating on the inside surface of the lamps. Before undocking, the third crew reported that the lights were again approaching the replacement level of illumination.

Displays.- Internal lighting is provided to illuminate the various panel meters and displays throughout the laboratory. The meter panel internal lights proved necessary in order to read the meters whenever power requirements or operations dictated a low lighting level. At high laboratory lighting levels, meter lighting was not required. The various colored lights which indicated system status sometimes appeared very bright and distracting during periods of operation at low light levels. The crew suggested that the capability to dim these lights would be desirable. They also stated that they would like to operate the light controls in the docking adapter while seated at the solar observatory control and display console, as operations at this console required frequent changes in illumination levels.

Portable Illumination.- Three low power and two high intensity portable lights are provided (fig. 10-44). The low power light uses a replaceable fluorescent lamp identical to those in the general illumination floodlight, but mounted in a protective case. It has two light levels, 12.5 watts and 9 watts, selected by operating a switch mounted on the case. The high intensity light is a wire cage enclosure with four permanently installed high wattage fluorescent lamps used in pairs. Each pair can be switched to high (75 watts) or low (40 watts). The two pairs may be used at the same time on high power to provide 150 watts. Detailed information on this light may be found in references 46 and 47.

The crew used the portable lights where required by attaching them to universal mounts and fastening the mounts to various structural members. The crewmen reported that they all used the portable low power lights at some time during the mission. The only difficulty encountered was in locating the proper connecting cables. They stated that these cables should be color coded and include cable caddies with internal locks.

The high intensity lights were used for television and movie camera operation as required by the flight plans (fig. 5-14). The crew reported that, for best results, maneuvering the lights was required, as they were quite directional and created dark shadows. Maximum lighting was used for all scenes and provided good results. The controls were behind the lights and difficult to see. Extended use of the high intensity lights in certain areas resulted in locally elevated temperatures.

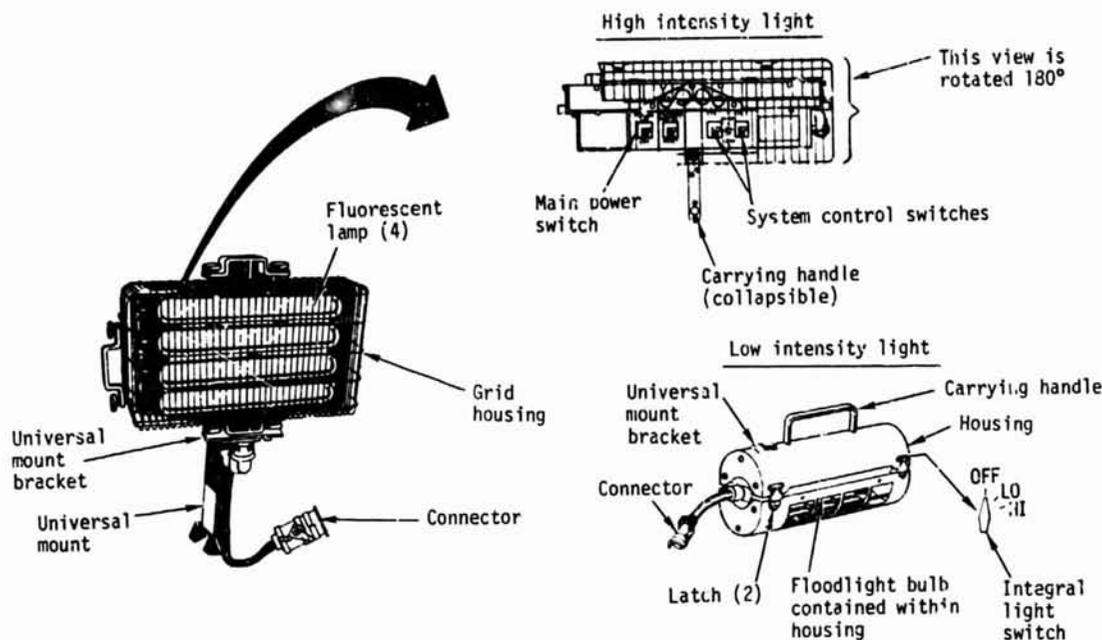


Figure 10-44.- Portable lights.

Although it was not considered a portable illumination device, the crewmen used the head-mounted lamp from the medical kit to perform some maintenance tasks, especially in the unlighted plenum area. This lamp provided enough light for general tasks (fig. 10-45).

#### 10.1.13 Crew Communications

Communication between crewmen within Skylab and between the crew and the ground is provided by an audio system (fig. 10-46), which consists of communications facilities located at crew stations throughout the laboratory. Interconnecting cables also provide a communication capability between the laboratory and module and the Saturn Workshop. Vocal or unaided communication between crewmen is also possible within the acoustical limitations of the laboratory configuration and the reduced atmospheric pressure.

**Audio System.**- There are 10 speaker intercom assemblies located in the workshop and 3 in the docking adapter. Each intercom has a built-in speaker and microphone with a volume control and switches to allow selection of audio channels, tape recording, radio, or intercom transmission. A green advisory light indicates tape recorder operation, and a red master alarm light is illuminated by the caution and warning system. Accessory equipment may be connected at the intercom to provide remote operating capability. Audio system operation is described in detail in 5.3.

For intravehicular pressure-suited operations or operations when the constant wear garment and biomedical vest are used, a communications carrier is connected to the intercom by a 15-foot crew communications umbilical cable. This transmits voice, biomedical data, and caution and warning information between the crewman and the audio system. The umbilical has a control head with a push-to-talk transmit switch and volume control. A separate 15-foot lightweight

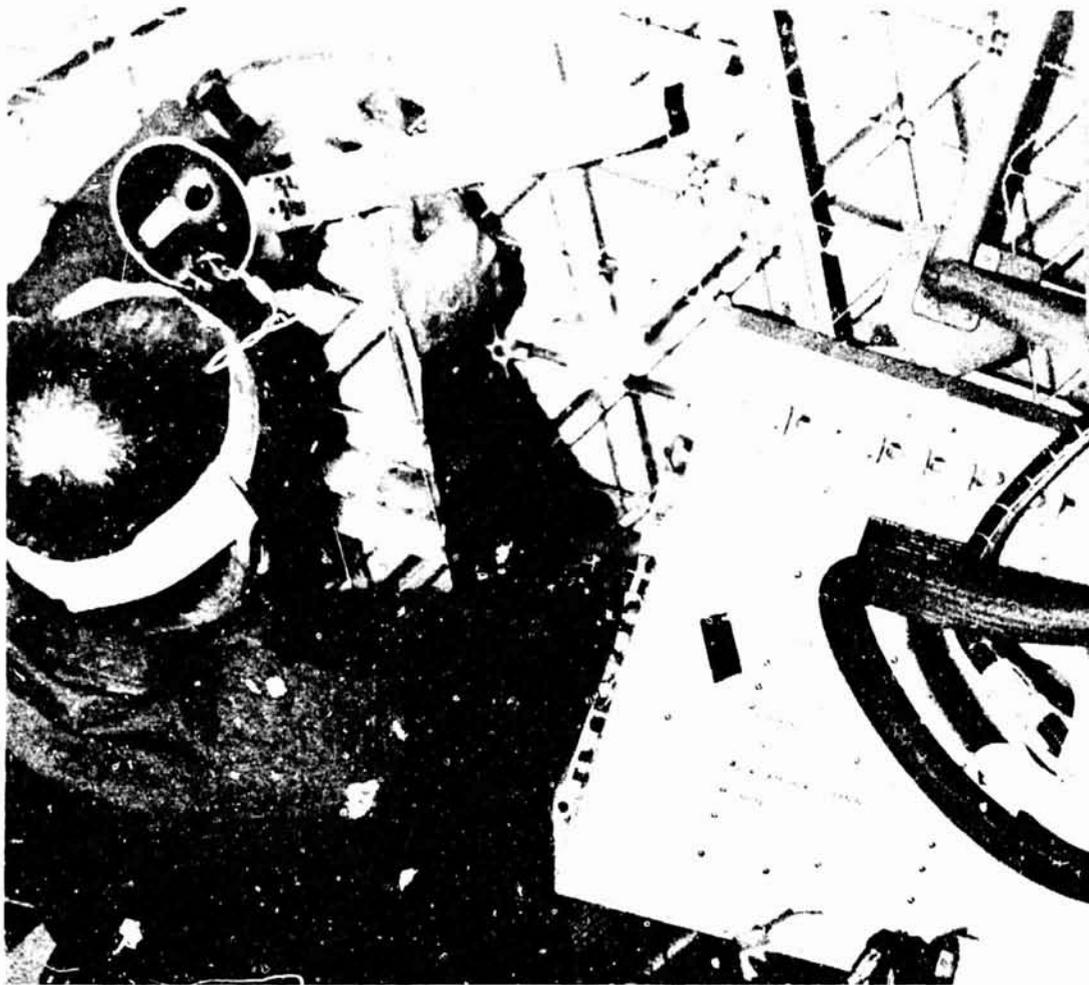


Figure 10-45.- Crewman using head-mounted lamp to disassemble the video tape recorder.

communications umbilical, a control head, and a lightweight headset are provided for general purpose use during crew work periods. These units connect to the intercom and carry voice communications and caution and warning tones only. Two extravehicular activity panels in the lock compartment and an intravehicular activity panel in the structural transition section include communications provisions for the pressure-suited crewman during extravehicular activities. The life support umbilicals include a cable which connects the crewman's communications carrier into the audio system through the panels.

The crewmen generally used the audio system hardware as planned. They used the intercoms primarily for ground communications and conversation within the laboratory, and the headsets for recording during experiment operation, television press conferences, and the astronaut maneuvering unit operations (fig. 5-14). Use of the headset did not turn off the speaker in the intercom. This caused some interference and annoyance to nearby crewmen engaged in other activities. Stiffness in the umbilical cables also tended to dislodge the headset. An acoustical feedback problem between some of the intercoms annoyed the crew because constant volume control readjustments were required on the intercoms.

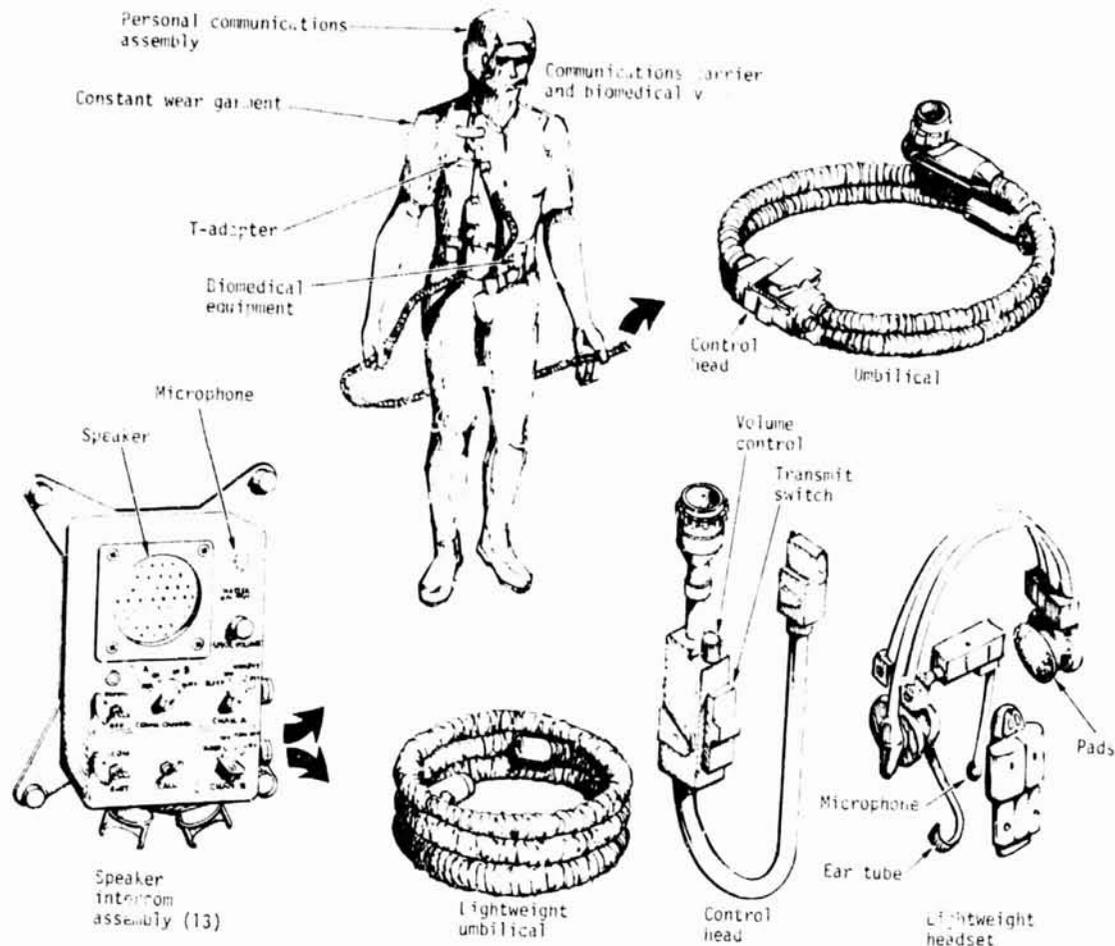


Figure 10-46.- Crew communications equipment.

This required changes in operating procedure as discussed in 5.3. The third crew carried up and installed an attenuation device that greatly improved the situation. Occasional loss of information occurred when the crew attempted to record while the ground was playing back tapes, even though playback was normally announced to the crew and the green advisory light on the intercom would go off. The quantity and location of the intercoms were adequate and volume levels were good. With the exception of the feedback problem, the radio system was satisfactory.

Direct Communications.- Unaided voice communication was somewhat difficult, and normal conversation was limited to distances of about 5 feet. The crew could make themselves heard in the workshop from the docking adapter by shouting, but normal voice communication was impossible. In confined areas such as the wardroom there was a tendency to get "close to the guy you were talking to." Communication between the wardroom or experiment compartment and the dome area was possible, but required "yelling." The crew concluded that this condition was due to poor sound transmission in the 5 psia atmosphere rather than to noise interference, which was low within the laboratory. The measured noise level was 55 to 60 decibels, well below the specified maximum level of 72.5 decibels.

## 10.2 CONTROLS AND DISPLAYS

Controls and displays include a variety of equipment located throughout the laboratory and are the direct interface between the crew and hardware systems. Controls, such as toggle switches, pushbuttons, circuit breakers, and hand-operated valves, are operated by the crew to bring about equipment or performance changes. Displays provide information to the crew concerning the operation and status of a system or subsystem. These include meters, indicator lights, gages, and video displays. Some control panels provide the option of ground control or onboard control of laboratory systems and equipment, with primary control capability given to the crew during manned periods. Other control functions that do not affect manned phases, such as 2-watt transmitter selection, belong to the ground. Nomenclature and labeling identify the controls and displays to facilitate communication and documentation reference and to ensure rapid and positive recognition. Color coding of selected controls is used to emphasize the specific nature of those controls to the crew. Emergency controls are indicated by red. A black and yellow cautionary striped band denotes a crew interface that should be used with caution and adequate preparation. Controls requiring unusual manipulation are marked with operating instructions. Although many controls and displays are located at the individual hardware items or systems, the majority are included in panels or consoles in the workshop, airlock, and docking adapter.

Workshop.- All control and display functions which could feasibly be located in a single place are on the electrical control console in the experiment compartment (fig. 2-9). The remaining controls and displays are installed at their use location so that operating status may be easily detected at the control operating position. There were no specific adverse or critical crew comments regarding the workshop controls and displays. Several false alarm indications that occurred during the mission are discussed in 5.5. The first crew indicated that the use of wickets and partial recesses for preventing inadvertent switch and circuit breaker operation was a good concept. The second crew commented that finger clearances between these devices and the controls were adequate.

Airlock.- The primary controls and displays for laboratory atmosphere and laboratory electrical power system operations are located on panels in the structural transition section (fig. 4-1, 7-18, and 7-19). Control positions are shown by indicator lights for momentary switches or detents and by pointers for valves and rotary switches. Bar guards provide switch protection and operating reaction points. Circuit breakers are grouped by function and system. Schematic and functional flow diagrams are superimposed directly on control panels where there is space or on adjacent areas. Meters are located next to their related controls. Switches controlling critical functions on these panels and the extravehicular activity control panels in the lock compartment are lever-lock type toggle switches to prevent unintentional operation by a pressure-suited crewman.

Control capabilities of the electrical power system enabled isolation of the laboratory batteries until the crew deployed the solar array wing. Subsequent adjustments permitted full use of the system with only the one wing. The capability of the crew to select coolant pumps allowed uninterrupted operation when the solar observatory coolant loop indicated malfunctions. Individual control of regulators on the cabin atmosphere control panel enabled the crew to manipulate them to correct nitrogen pressure regulation problems. Visual alarms and annunciators in the caution and warning system were adequate to prompt proper crew reaction and provide system troubleshooting capability. Occasionally circuit breakers were inadvertently operated, apparently because of the close

proximity between the panels and the heavy crew traffic in an area where passing crewmen often changed their body position or trajectory. The circuit breaker bar guards used did not prevent a stray shoe tip or finger from moving the toggle-lever type switches. Although these breakers were superior when used regularly for switching functions, push-pull type breakers would have been preferable for infrequent usage.

Docking Adapter.- A number of control and display panels are located in the docking adapter. These are primarily associated with operation of the various experiment systems. However, the solar observatory control and display console includes controls for Skylab attitude and solar observatory electrical power. The console is the most complex scientific control and display equipment flown to date on an orbital mission (fig. 10-2). It is designed for performing sophisticated solar physics observations using eight telescopes. Controls include toggle and rotary switches, a "joy-stick" manual pointing controller, and a keyboard digital address system. Systems monitoring is provided by status lights and flags, alert lights, dual scale meters, pulse counters, digital displays, an activity history plotter, and two video displays. Experiment controls and displays are centrally located in a row-column matrix configuration wherein rows contain individual experiment controls and displays and columns contain controls and displays having a common function. Subsystem controls and displays are functionally grouped around the periphery area.

The crew spent many hours at the console performing the solar physics experiments. The highest incidence of interface problems with the console occurred on the experiment operations controls and displays. The crew noted numerous instances when they inadvertently left a three-position toggle switch in the wrong position for no apparent reason. This switch has no position-indicating display and relies on the operator's visual reference. A crewman looking straight onto the panel at some angle below the eye reference point may be unable to distinguish the actual position the switch is in.

One experiment's ready-operate light failed, so the crew could not determine when the experiment was actually in an operating mode. An auxiliary timer was installed by the third crew to rectify this problem. The crew also found the colors and illumination levels of these lights very annoying. The alert status lights were intended to indicate any abnormal and potentially critical system condition, such as high control gyro bearing temperatures and improper aperture door positions. Malfunctions persisted in some of these systems throughout the mission. This caused extensive confusion, because when a new alert would illuminate, the crewman could not detect its presence among the surrounding colored lights, which rendered the system ineffective. The crew covered the indicators of malfunctioned equipment with masking tape to eliminate the problem. The grey and white indicators on status flags should have had more contrast for visibility.

The crew performed very much as they did during their simulator training, and the habits formulated then never changed. The most desired change in the console was in its structural configuration. A "wrap-around" style would have made controls and displays easier to see and reach. Although there were a number of hardware problems and procedural errors, the amount of valuable solar physics data collected far exceeded premission expectations.

### 10.3 CREW OPERATION OF EXPERIMENTS

The operation of experiments was generally satisfactory, and most experiments met or exceeded their premission objectives. The human factors problems are discussed here, and a description of the experiments and the system problems is contained in section 12.

The scientific airlock system was operated efficiently and easily by the crew. It was tight and never failed a leak check. More time than expected was needed for pressurizing and depressurizing, which the crew had never practiced during training. Consequently, some lead time was necessary to set up an experiment. No difficulties were experienced aligning experiments in the airlock, and no flanges or seals were damaged. While using the scientific airlock as a vacuum source to perform a condensate holding tank dump, one of the crewmen left the outer door open and the valve in the pressurization position. With the desiccant system valve in the open position, cabin air bled overboard through the desiccant canister and out of the airlock. The leak was discovered by the ground controllers and the crew was asked to configure the airlock properly.

Handling the contamination measuring experiment instrument was a one-man operation and was facilitated by the handle of the canister being located through the center of gravity. As operations progressed, the crew noticed that the photometer extension rods for use with the airlock became increasingly difficult to screw together. This was thought to be caused by a buildup of moisture and contamination. During rod retraction, the thermal gloves were required but did not hinder rod retraction operations. The second crew indicated that the system should have been checked out completely and possibly operated inside the workshop before its use.

The ultraviolet panorama experiment activation and manipulation was easily a one-man operation. The latching technique and decals on the launch stowage structure were adequate. However, the schedules did not allow enough time between exposures. One minute was added to these times to allow for adjustments in pointing and timing for the upcoming exposure. The crew also said the schedule did not allow time to debrief previous experiments before starting. There were no problems associated with the workshop lighting levels during operations.

The far ultraviolet electronographic camera experiment operations were performed as scheduled, and procedures and equipment were adequate. While performing the experiment through the scientific airlock, the crew noted that the green exposure sequence indicator light was actually brownish red and very low in brightness and thus would probably be difficult to read during extravehicular operations. During the second extravehicular activity of the third manned period, three data takes were made even though the crew could not see Comet Kohoutek. It was hoped that the comet would be detectable on the photographic data.

The crew reported that the barium plasma observations experiment setup was a lengthy operation and took approximately 2 hours to complete. The barium injection was visible to the naked eye and was photographed using numerous time exposures. During these photographic sessions, there were some difficulties in damping the oscillations of the camera mount after exposure actuation. As the experiment progressed and techniques improved, these oscillations were reduced.

The Kohoutek photometric photography experiment was performed at the designated times in the third manned period to obtain photographs of Comet Kohoutek.

Not all scheduled photographic exposures could be made because of limitations in the window's field of view and the faintness of the comet.

During replacement of the thermal control coating experiment sample, it was difficult to align the snaps because the extravehicular glove restricted visibility and dexterity. The panel was eventually attached by touching the center samples with the gloved finger, possibly contaminating them. Although the experiment was not designed for replacement in orbit, the problem could possibly have been eliminated with the addition of guide pins and alignment marks. The samples were easily retrieved. The crew stated that the overall design of the experiment hardware was adequate, but they felt that a heel restraint would have been helpful for stabilization when retrieving samples.

The materials processing experiment operation was similar to ground training except for the time required to heat or cool the specimen and to obtain a sufficient vacuum in the facility. The crew stated that the training unit was excellent and identical to the flight unit. Since they had never evacuated the facility during training, the crew thought that the slow bleed-down the first time the vacuum gage was used indicated a faulty gage. They experienced no problems in handling the specimens as long as they observed proper cooldown time.

The crew enjoyed performing the electric furnace experiment. The equipment worked as designed and was easily installed into the materials processing chamber. The specimen cartridges were very well identified to permit coordination of sample data. The operations were clearly defined, and no problems were experienced.

The manual navigation sightings experiment window hood, which was used to shield the wardroom window from internal reflection, was considered a definite necessity. The crewman found it difficult to hold the sextant steady during sightings, and emphasized the importance of body position and posture in obtaining accurate sightings. During an early operation, one crewman developed muscle cramps in his arms and legs. He devised a restraint system to hold him in position at the window, using a long strap hooked over a bar, and felt this improved the accuracy of his sightings. There was a distinct difference in ease, ability, and accuracy of the operation, depending on whether the stars were located up and down or left to right relative to his body posture.

It was difficult for crewmen to remove their fingers from the pointing control knobs on the sextant without moving it. They could get a good alignment, but when they released their fingers, the knob would move slightly. The control knobs should be easy to move, but not so sensitive. The crew also disliked the design of the knobs on the filters because they could not tell whether the filters were in or out. The crew experienced pointing difficulties because the shape of the case and the location of the strap made it difficult to hold the sextant in the proper position at the window. They felt they needed phosphorescent alignment marks to get the line of sight directed between two stars. They also suggested the use of a colored filter so that they would not lose track of the particular star they were sighting, which was a problem when holding the sextant at odd angles. The system should have been designed so that all controls could be operated without the crewman removing his eyes from the reticle sight. Having the sextant readout inside the reticle would prevent losing sight of the star while taking readings.

The inflight aerosol analysis data cards were not large enough to allow sufficient area to record all the required information.

#### 10.4 INFLIGHT MAINTENANCE

The feasibility of performing inflight maintenance, and the value of this capability, was effectively demonstrated as successful repairs during the first manned period in effect saved the mission. Procedures and hardware were developed on the ground, and crewmen practiced in trainers and the neutral buoyancy simulator to perform tasks which had been considered impractical or infeasible prior to the mission. The continuing degradation or failure of certain equipment also resulted in the planning of additional maintenance activities which were carried out during the second and third manned periods.

Initial Saturn Workshop design concepts depended on the use of high-reliability hardware and excluded the requirements for inflight maintenance. As systems increased in magnitude and complexity and the mission lengthened, it became apparent that, even with high-reliability hardware, failures could occur, jeopardizing the crew and the mission objectives. The philosophy gradually evolved to a concept of providing for considerable maintenance, but with a number of limitations, such as no maintenance on electrical circuits and none during extravehicular activities. Provisions were made for three categories of inflight maintenance: scheduled activities for normal cleaning and replacement tasks, unscheduled activities for anticipated repair and servicing of designated equipment, and a general capability for unexpected or contingency repairs.

Scheduled Inflight Maintenance.- This category was established for periodic cleaning or replacement of consumable, cycle-sensitive, or time-sensitive equipment (table 10-X). Requirements are included in the crew checklists as part of the normal housekeeping tasks, but are held to a minimum to conserve crew time. They are scheduled in the daily flight plans and generally include the cleaning or replacement of such items as waste system and environmental control filters. Scheduled maintenance tasks were performed much as planned. However, a few tasks were added, and the frequency of performance was varied as the mission progressed. No significant difficulties were reported in performing the tasks. Onboard tools, spares, and procedures were adequate for all tasks. The crew indicated that the tasks could have been performed efficiently with little or no training.

Unscheduled Inflight Maintenance.- Provisions are made for replacing failed components, installing auxiliary and backup hardware, and servicing and repairing certain equipment as required. Spare components, tools, and procedures are provided for performing 160 different unscheduled tasks, and the crew is trained to perform each. The selection of these tasks was based upon analysis of failure criticality, failure probability, failure effects on the mission and the crew, complexity of the required maintenance, support required, and time to perform the maintenance. Table 10-XI shows the unscheduled tasks planned and performed and spare components used. No significant problems were reported by the crew, and tools, spares, and procedures were adequate.

Contingency Inflight Maintenance.- In addition to the provisions for scheduled and unscheduled maintenance, tools and materials are included to permit repair of failed equipment for which no specific maintenance task could be anticipated. Items such as tape, wire, C-clamps, pliers, a vise, twine, hammers,

Table 10-X.- Scheduled Inflight Maintenance Activities

Task description	Planned frequency of performance	Actual frequency of performance during manned periods		
		First	Second	Third
<b>Vacuum cleaning tasks</b>				
<b>Atmosphere inlet screens:</b>				
Air mixing chamber, airlock and docking adapter fans	7 days	7 days	3 days	2 days
<b>Waste management compartment:</b>				
Debris coarse filter	7 days	7 days	3 days	
Debris coarse-fine filter	Added			2 days
Debris fine filter	Added	7 days	3 days	2 days
Workshop heat exchanger fans	Added			6 days
Workshop heat exchanger vanes	Added			2 days
Workshop vent valve filter	Activation, 2nd and 3rd manned periods		Acti- vation	Acti- vation
<b>Replacement tasks</b>				
<b>Waste management compartment:</b>				
Vent unit fine filter	7 days	7 days	12 days	12 days
Vent coarse-fine filter	28 days	Day 39	Day 134	Day 214
Filter and charcoal cartridge	28 days	Day 39	Day 134	Day 213
Fecal collector filter	28 days	28 days	28 days	28 days
Urine separator filter	28 days	-	-	-
Urine separator	Deactivation, 1st and 2nd manned periods	Deacti- vation	Deacti- vation	
<b>Shower filter</b>				
Molecular sieve solids traps	7 days	Following crew showers		
Molecular sieve charcoal canister	11 days	11 days	11 days	11 days
Carbon dioxide detector cartridges - inlet	28 days	28 days	28 days	28 days
- outlet	14 days	14 days	14 days	14 days
Oxygen partial pressure sensor	28 days	14 days	14 days	14 days
	Activation, 2nd and 3rd manned periods		Acti- vation	Acti- vation
Console coolant water filter	Before and after Earth observation experiment operation, 1st manned period	Day 15 Day 36	Day 133	Day 236
Airlock gas coolant separator	Activation, 2nd and 3rd manned periods		-	-

and tweezers are included in the tool inventory for this purpose. During the mission, additional tools and equipment were launched with the crews to troubleshoot and correct malfunctions for which onboard maintenance support was inadequate. Other contingency situations occurred that were resolved with the onboard support equipment, but required that step-by-step procedures be developed on the ground and transmitted to the crew. The following paragraphs relate, in chronological order, the contingency inflight maintenance tasks performed by the crew.

On Day 13, the crew successfully deployed a parasol thermal shield, carried in their command module, from the +Z scientific airlock to lower temperatures in the workshop and make it habitable (fig. 3-11). The parasol thermal shield consisted of four spring-loaded, telescoping ribs and a folded shield stowed in a modified experiment canister. The canister was installed in the scientific airlock and the parasol extended by means of a center extension-retraction rod to a distance of 21 feet from the workshop, at which point the parasol opened

Task description	Number of spares onboard (available)	Number of spares resupplied	Spare used or last performed		
			1	2	3
<u>Electrical system parts replacement</u>					
S190 window heater control unit	0 (1)				
Airlock 10-watt light bulb	0 (1)				
Airlock 10-watt light bulb	120				
Floodlight bulb	6 (6)				
Urine separator cable	1				
Docking adapter power umbilical	1				
<u>Electrical system installation</u>					
Install docking adapter umbilical					
Install contingency power cable	1				
<u>Structural parts replacement</u>					
Install docking adapter vent plug	4				
Docking adapter hatch seal	1				
<u>Structural failure, repair or adjustment</u>					
Open docking adapter hatch					
Structural leakage					
Release jammed stowage locker doors					
Open works'op hatch					
Open airlock forward hatch					
Open airlock observatory aperture doors					
Open film vault doors					
Remove electrical pins					
Remove expendable pin					
Release docking latches					
Install airlock window cover cap					
Adjust food freezer door hinge					
Manually declinch solar observatory solar arrays					
Disassemble scientific airlock tripod					
Expendable grip pin					
<u>Crew equipment servicing</u>					
Repair or replace shoe indicating cleat					
Lubricate sleep restraint zipper	2				
Replace food trays (lily) unit seals					
Repair and maintain maintenance and bladder repair					
Clean and antifog treat helmet					
<u>Experiments part replacement</u>					
Console precision clock	0 (1)				
Mass measuring device (M074-M172)	3				
Vectorcardiogram cable (M093)	3				
Electrode harness kit (M053)	1				
Subject interface box (M092-M093)	1				
Pressure waist seal (M092)	1				
Body temperature probe (M171)	1				
Body temperature probe (M171)	1				
Brushing brush (M171)	1				
Erpomaster drive assembly (M171)	15				
Batteries (M487)	3				
Magazine drive assembly (S190)	18				
De-siccant assembly (S190)	1				
Film magazine (S190)	1				
Film cassette (S190)	1				
Center-down-detector (S192)	1				
Percent and studmaster batteries (T002)	2				
<u>Experiments installation and repair</u>					
Camera filter (S020)	2				
Shutter operator (S054)	4				
Connect backup digital address system	Installed				
Connect backup radio noise burst monitor	Installed				
Di-connect shutter drive (S190)	1				
Install primary signal attenuator (S192)	1				
Install secondary signal attenuator (S192)	1				
Connect spare tape recorder (S192)	1				
Connect spare tape recorder (S192)	1				
Repair battery vent line (M512)	1				
Foot restraint (T013)	1				

Task description	Number of spares onboard (available)	Number of spares resupplied	Spare used or last performed		
			1	2	3
<u>Water system parts replacement</u>					
Power modules (B lower units)	1				
Trash airlock hatch and other seals	14				
Waste processor control panel	1				
Waste processor screen and seals	6				
Waste processor pressure mechanism	1				
Masticloth squeezer (flapper valve)	1				
Masticloth squeezer seal	1				
Urine separator hoses and seals	5				
Urine separator support and filter	2				
Urine and shower separator motors	1				
Urine collector pressure device	1				
Urine volume measuring device	1				
Urine bag housing	1				
Crimper-cutter-door assembly	2				
Fecal collector balloons and liner					
<u>Water system servicing</u>					
Release jammed trash airlock ejector					
Clean trash airlock vent valve filter					
Remove and clean "rain" airlock cylinder screen					
<u>Waste system parts replacement</u>					
Handwasher hot water dispenser	2				
Drinking water dispenser	1				
Food reconstitution water dispenser valve	1				
Food reconstitution water dispenser valve	1				
Flush water dispenser	9				
Handroom water hose	2				
Handroom water hose	1				
Water system couplings and seals	8				
<u>Water system servicing and deservicing</u>					
Pressure suit umbilicals and control units					
Console coolant loop					
Pressure suit umbilical system					
<u>Atmosphere system parts replacement</u>					
Molecular sieve fan	8 (1)				
Molecular sieve solids trap (pair)	2				
Molecular sieve charcoal canister	0 (2)				
Waste management compartment filters	3 (1)				
Food exchanger water separator plates	4				
Control panel water separator plates	1 (1)				
Workshop thermal control heater					
<u>Atmosphere system repair</u>					
Docking adapter-command module flexible duct					
Workshop duct					
<u>Instrumentation and communications</u>					
<u>System parts replacement</u>					
Powerline intercom assembly	2 (2)				
Powerline intercom assembly	16 (24)				
Powerline intercom assembly					
Crewman communication umbilical					
Control head and cable					
Get timer					
Dosimeter monitoring assembly					
Fire sensor	1				
Indicator lamp for above	6				
Indicator lamp for above	2				
Telegripner assembly	8				
Telegripner assembly and paper spoon	1				
Carbon dioxide detector end plate	2				
Video switch	1				
Television input station	1				
Video tape recorder	1				
Laboratory tape recorder	1				
Color television camera	4				
Television monitor	1				
Television power cable	1				
Television power cable	1				
Flowmeter transducer	0 (1)				
Communications carrier	1				
Docking adapter control umbilicals					
<u>Instrumentation and communications system installation</u>					
Video switch power cable	0 (4)				
Television contingency for cables					
Command transfer unit					

out. The center rod was then retracted to bring the shield to a standoff position close to the workshop's outer surface.

The ultraviolet stellar astronomy articulating mirror system gear mechanism jammed and was disassembled on Day 18 so that a metal tab could be bent out of the way of the gears. The ergometer experiment pedals were lubricated with the tool kit general purpose lubricant on Day 22 to reduce squeaking during operation.

The workshop solar array wing 1 was deployed during an extravehicular activity on Day 25 (3.3.2), using onboard tools and equipment and other tools brought up in the command module. This was accomplished with very little deviation from the procedures developed on the ground and transmitted to the crew. Equipment setup and translation present'd no problems. After attaching the cable cutter, the Commander translated to the wing vent module and attached one of the hooks of a beam erection tether, which had been fabricated from onboard thermal shield hardware. With both crewmen at the fixed airlock shroud area, the Science Pilot attempted to pull the cable cutter rope and cut the debris strap. After several pulls without success, the Commander translated to the debris strap to examine the cutter jaws. As the Commander reached the area, the cutter severed the strap, the beam moved out about 2 feet, and the tether became slack. This resulted in an unstable restraint condition and some gyrations for the Commander, as he grabbed the tether and pulled himself back to the shroud. The two crewmen pulled the slack from the tether and attempted to pull the beam to an erect position. When this was unsuccessful, the Commander again translated to the beam hinge and lifted the tether to his shoulder, facing the shroud (fig. 10-47). With both crewmen applying significant force to the tether, the beam actuator clevis broke (4.2.1), releasing the beam and causing another unstable restraint condition for both crewmen. This was not serious, however, and they were soon restrained at the disccone antenna boom area. The

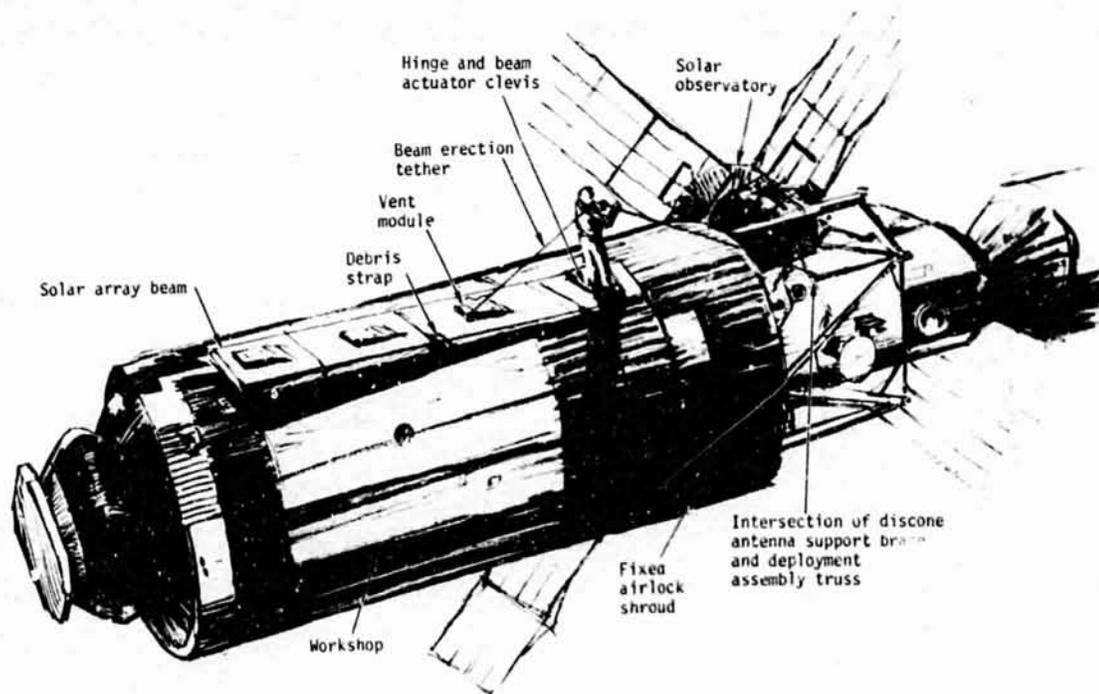


Figure 10-47.- Solar array beam deployment technique.

return to the airlock and the disassembly and stowage of the deployment hardware were accomplished with no difficulty.

Because the experiment tripod was needed to support the parasol container, a backup unit had been stowed in the command module. The backup tripod did not fit the mounting provisions properly, so on Day 29 the crew used attaching hardware, salvaged from throwaway launch restraints, to mount the tripod. During the extravehicular activity on Day 39, a crewman struck power conditioner 15 with a hammer to free a stuck relay and restore battery charging regulation.

The twin-pole thermal shield was deployed over the parasol during the first extravehicular activity by the second crew on Day 85. The shield and all equipment necessary for deployment had been developed, tested, and launched with the first crew. Two crewmen passed the equipment through the extravehicular activity hatch into the fixed airlock shroud area. Using the film transfer boom, they transferred a foot restraint assembly, the pole baseplate, and the packaged shield to the solar observatory A-frame outrigger structure. The foot restraint was locked in place and one crewman installed the baseplate on the outrigger while the other crewman assembled the pole sections and clotheslines. As the 11 sections forming each pole were assembled, the crewman on the outrigger locked them into the baseplate. The shield bag was opened and the shield was attached with hooks to rings on the clothesline. The shield was hoisted like a sail to the ends of the twin poles, and the whole assembly was swung toward the exposed area of the workshop and locked. Two reefing lines at the corners of the shield nearest the solar observatory were secured to the outriggers, completing the shield deployment (fig. 10-48). The installation was not difficult, and no major problems were encountered.

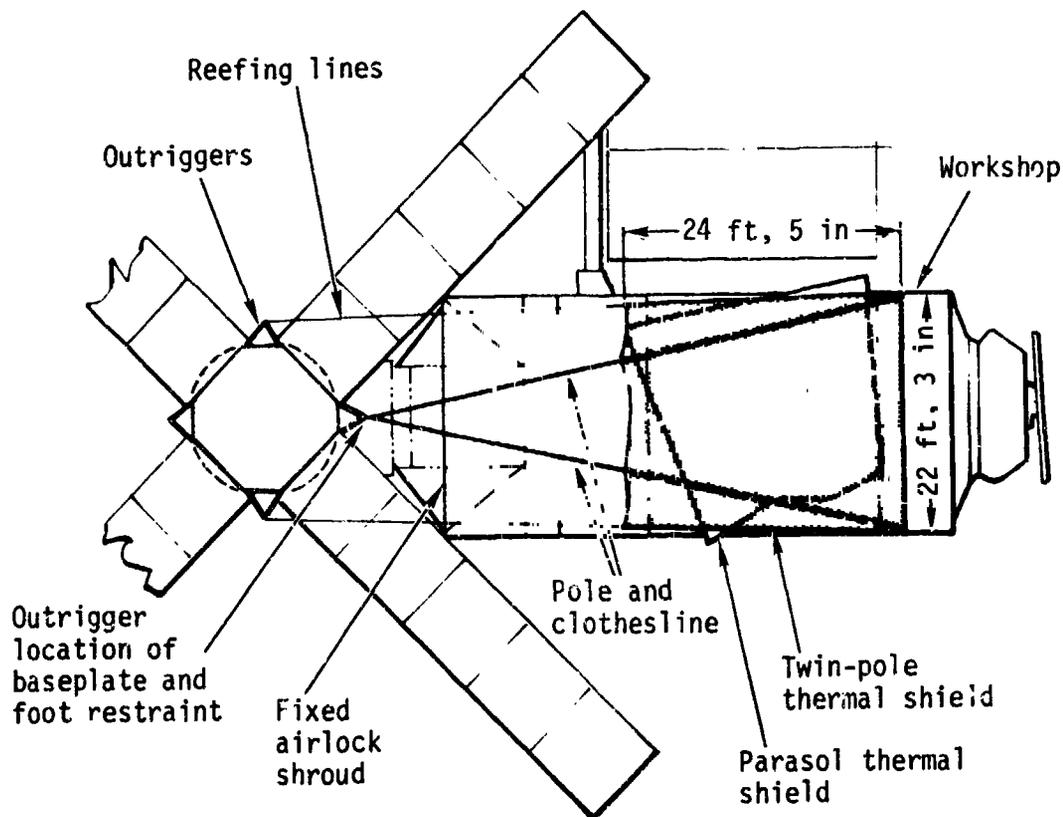


Figure 10-48.- Thermal shield deployment configuration.

After deploying the thermal shield, the crew removed the latch ramp from one solar observatory experiment aperture door latch mechanism to eliminate binding of the door during opening and closing. Two bolts that secured the latch ramp were removed with a wrench from the tool kit. On Days 90 and 95 the laboratory tape recorders were disassembled and the cause of failure was isolated to a worn drive belt. All tools necessary for this task were available onboard. The crew reported on Day 98 that the rope on the Mark I exerciser had broken. The crew successfully replaced the rope in accordance with an uplinked procedure, but had to improvise in tightening a clamp screw, because the tool kit did not contain the proper size hex wrench. An attempt was made on Day 99 to isolate air leakage in the condensate dump system by pressurizing the system and bubble-checking the plumbing joints with a soap and water solution. The leak was not located, but it stopped after replacement of the dump probe.

A visual inspection of laboratory coolant loop lines and fittings was performed in two phases on Days 99 and 101, after excessive loss of coolant was detected. The crew removed a number of structural panels to gain access to the plumbing, but found no internal leakage. The supplementary rate gyro package, or "six-pack," developed during the second unmanned period, was installed and activated on Day 103 in a combined extravehicular and intravehicular activity. All tools and equipment necessary for installation and checkout were included with the six-pack. The crew also removed two more aperture door latch ramps to eliminate binding, using the same procedure as before. A screw from one of the ergometer pedals, which had loosened and become lost, was replaced from an assortment of spare screws on board on Day 107. The new screw was broken during installation and the file blade of the Swiss army knife was used to slot the screw so that it could be removed with a screwdriver. A second screw was removed from a spare urine separator and successfully installed in the pedal.

Low airflow in the ventilation ducts was corrected on Day 111 by vacuum-cleaning the heat exchangers. An adjustment to the multispectral scanner experiment was successfully performed on Day 113 to correct a film overexposure problem which had occurred during the first manned period. A tool kit screwdriver blade had to be filed down with the Swiss army knife file blade so that it would fit the adjusting screw. Four printed circuit boards were removed from the video tape recorder on Day 117 to be returned for failure analysis (fig. 10-45). The crew also performed a troubleshooting procedure on Day 117 to determine the condition of the condensate dump probe removed on Day 111 because of ice accumulation. Checkout of the probe heaters using the digital multimeter revealed that the heaters had not failed, and the probe was restowed for use as a spare.

During deactivation by the second crew, one of the three urine drawer seals became unbonded. Three spare seals were carried up with the third crew, and the failed seal was replaced on Day 188 during activation of the urine system. The third crew also carried up servicing equipment and written procedures developed during the third unmanned period to restore operation of the primary laboratory coolant loop. On Day 190 the crew successfully tapped the lines to refill the system with coolant and restored it to satisfactory operation. Liquid crystal thermometers, backed with pressure-sensitive adhesive, were attached to each of the six-pack rate gyros on Day 192 to facilitate the monitoring of gyro temperatures. A failure in the microwave radiometer, scatterometer, and altimeter experiment antenna control electronics during the second manned period resulted in an extravehicular maintenance activity for the third crew on Day 193. They had to reach the antenna on the -Z axis of the docking adapter without

the use of installed translation aids and restraint , since the path was not along the normal extravehicular activity route. A portable pressure garment foot restraint and universal mount were mounted at the antenna location to provide a fixed crew restraint. The crewmen installed a jumper box and inhibit switch in the antenna circuitry and a lock assembly on the antenna's pitch gimbal.

A solar observatory console video monitor, which had failed during the second manned period, was replaced on Day 196 by a spare unit provided with the third crew. Special tools, cables, and procedures had to be developed and supplied with the spare monitor. The second crew had found that more accurate timing was required for spectrograph experiment operation, but an attempt to remove the console kickplate in preparation for this activity was unsuccessful. An auxiliary slit timer was developed for installation by the third crew, as well as a special tool to remove the screws from the kickplate. On Day 196, the timer was installed by the third crew and the cable connectors were mated without having to remove the kickplate. This was done with a pair of special connector pliers which had been developed for the rate gyro installation. A replacement motor was installed on Day 197 to restore the nuclear emulsion experiment detector package deployment drive, which had failed in the first manned period. A repair kit consisting of a rope, a spring, and a hex wrench was used to repair the Mark I exerciser on Day 206. This replaced the temporary repair made by the second crew. A drop in the solar observatory coolant loop flowrate was corrected on Day 219 by temporarily installing one of the spare liquid-gas separators to filter out possible contamination and gas bubbles in the system. The procedure was repeated again on Day 236. A maintenance activity was performed during the extravehicular activity on Day 226 to move the X-ray spectrographic telescope experiment filter wheel manually to the "clear aperture" position. This required working through the open door in the solar observatory canister with an inspection mirror, a flashlight, and a long screwdriver.

Experience on the Saturn Workshop has shown that extravehicular maintenance is necessary for space missions and should be given the same consideration during planning as intravehicular maintenance. Most of the extravehicular maintenance performed was accomplished with real-time planning and without the assistance of built-in translation aids, restraints, or tools intended for such applications. Contingency inflight maintenance also demonstrated that access to equipment, attaching hardware, electrical connections, and plumbing is imperative, even in areas where maintenance is not anticipated. The crew indicated that the routine tasks and procedures were so well planned and documented that many of the maintenance tasks could have been performed efficiently with little or no maintenance training. Such training should be limited to complex repair tasks that involve unusual equipment disassembly techniques or tasks which could present a hazard to the crew or could result in damage to spacecraft equipment.

Handling, alignment, and manipulation of large, heavy items presented no problems in zero gravity. Small items, such as bolts, screws, and washers, tended to float away and become lost. However, these items usually found their way to one of the air inlet screens.

Spares to support inflight maintenance should take into consideration non-critical and redundant hardware as well as single point failures. With the exception of the contingency maintenance performed, very few of the items replaced

were in the premission critical category. Spares for inflight maintenance should also include repair parts as well as replaceable assemblies.

For inflight maintenance purposes, the crew preferred the quick-release, locking screw fasteners and magnetic door latches instead of the twist strap and hook, ball locking pins, and expandable sleeved pins. Internal wrenching screws and hex-head bolts were the preferred types of attaching hardware. Slotted head type screws were unacceptable because they could not be easily removed.

Tools.- The tools and equipment onboard the Saturn Workshop are provided to support not only inflight maintenance, but also activation, operation, and deactivation of systems and experiments. Because of the limited stowage capability, the majority of the tools are selected to perform specific tasks. As a result, full sets of wrenches, sockets, hex wrenches, and screwdrivers are not provided. However, some spare tools are provided where justified by the number of applications and the susceptibility of tools to loss or breakage. The complement of tools and maintenance equipment is primarily contained in five kits. Most of these are located in the workshop stowage lockers. A locker in the docking adapter contains tools that may be needed during periods when the workshop is inaccessible, such as before workshop activation and during extravehicular activities. A tool box located on the forward side of the docking adapter axial hatch contains tools to disassemble the hatch in the event of latching mechanism jamming. A repair kit in the workshop contains the materials necessary to patch leaks within the habitation area and miscellaneous fastening materials and devices, such as tape, Velcro, and snaps. Additional special purpose kits, tools, materials, and equipment are located at various places in Skylab. These include a command module tool kit, tools for experiments, extravehicular mobility unit and pressure garment maintenance kits, water system servicing equipment, and miscellaneous spare tools and maintenance items. This inventory was surmised during the mission with items necessary to install auxiliary hardware to support contingency inflight maintenance, and to replace lost or broken

The crew used nearly all the tools provided in the tool kits. During the course of the mission, one ratchet handle failed, the diagonal cutters and a hex screwdriver bit were broken, and one pinch bar was lost when it was left tethered to the solar array wing during an extravehicular activity. It was not replaced, since two units were initially provided. The other broken tools were replaced with the launch of the next crew. Enough tools were provided to perform all planned activation, operational, and maintenance tasks. They also proved adequate for supporting most of the contingency maintenance tasks. As a result of the contingency activities performed, the crew recommended that a number of additional tools be provided, including a hacksaw, drill and drill bits, a file, larger screwdrivers, and a sharpening stone. The comment was made that the tools should include the normal types found in the home workshop and should be complete sets. The need for some type of workbench that would include features for holding tools and small parts as well as the component being repaired was also expressed.

Only a small number of tools were required to perform any one specific task; therefore, the crewmen did not remove the tool drawers for transportation to the worksite. The tool caddies, which were provided for carrying and restraining handtools, were used on several occasions but proved to be inadequate except for retaining the tools at the worksite. The Velcro failed to restrain the tools during translation and the crewmen carried most of the tools in their pockets.

They indicated that a tool caddy made of a transparent material to facilitate the location of the needed tool would be desirable. It should also be capable of holding small parts such as screws, nuts, and washers, since containing and locating these items was a problem in zero gravity. The patch of Velcro on the tools were of little value. The crew stated that specific classes of tools, such as sockets and drive accessories, open-end wrenches, hex wrenches, and screwdriver bits, were not located in separate drawers. They also indicated that the placement of tools and tool kits at numerous locations throughout the laboratory was undesirable. A tool summary or listing was not included and the crew was unaware that certain tools were available unless they were specified in a procedure.

None of the tools in the initial inventory were designed for extravehicular use. As a consequence, tape had to be used to enlarge tool handles and attach the necessary tethers. An adaptable extravehicular activity handle for standard tools and tether attach points would have been desirable.

#### 10.5 SOLAR OBSERVATORY FILM RETRIEVAL

Extravehicular activities are performed during the manned periods of the Skylab mission to retrieve and replace film in the solar observatory cameras. With one exception, all of the solar observatory experiments collect data on photographic film enclosed in magazines that require periodic replacement. The hardware discussed in this subsection includes all major equipment required for this task. Evaluation of the pressure suit and crew performance is contained in references 15, 16, and 17.

The film retrieval operations are performed from four work stations located in the fixed airlock shroud area and on the solar observatory structure. The fixed airlock shroud work station (fig. 10-49) contains the equipment for stowing and transferring the film magazines to and from the center and transfer work stations on the solar observatory. One crewman remains in the shroud area and the other performs the film replacement, moving between the center, transfer, and Sun-end work stations to obtain access to the various experiment film receptacles. Single handrails and a dual-rail ladder provide a translation path between the work stations. Each work station is equipped with combinations of single handrails for ingress, egress, and movement about the station. All equipment along the paths is fabricated without sharp corners or edges which might damage a crewman's pressure suit. Twenty-five incandescent light fixtures (18.75 watts each) are used to provide illumination levels of approximately 1.0 ft-lamberts along translation paths and 5.0 ft-lamberts at the work stations. There are 5 lights in the airlock shroud area, 6 on the deployment assembly, and 14 on the solar observatory. All airlock shroud and solar observatory lights are encased in a wire-grid enclosure to protect the bulb from damage. Those at the deployment assembly are enclosed in a metal box with a hole provided for directional lighting. Life support umbilical clamps are located at two of the work stations to facilitate management of the umbilicals during the extravehicular activity.

Fixed Airlock Shroud Work Station.- This area, along with the adjacent lock compartment, serves as a base camp for one crewman to monitor the other during all extravehicular operations, and has foot restraints, stowage locations for all hardware and tools, and film magazine transportation devices.

Two film transfer booms are provided to transport the film magazines to and from the center and transfer work stations. The booms are operated from a control panel at the work station and are electrically driven, tubular extendible

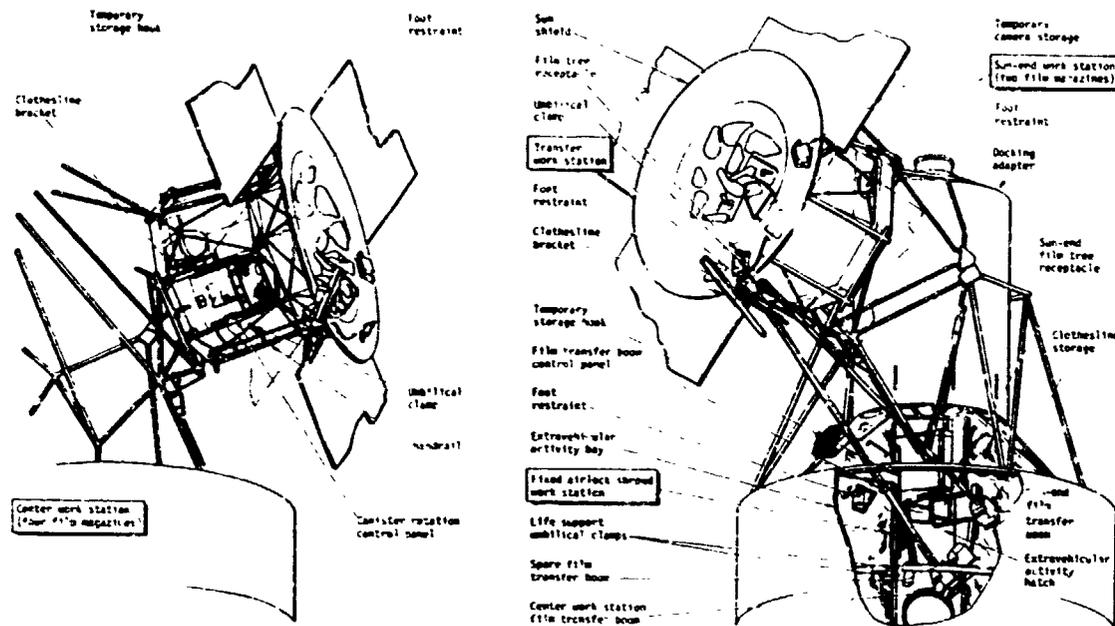


Figure 10-49.- Film retrieval work stations and support hardware.

devices with manual backup operation capability. In the event of total operational failure, a spare boom unit is provided and a toe-bar restraint for the crewman facilitates the changeout. Two film tree pallets are used to transfer film magazines from the laboratory to the work station through the hatch. Each tree inserts and locks into a receptacle within reach of the foot restraints. One of the trees attaches to a clamp-type hook on the end of the film transfer boom and is used to transport two film magazine containers to the transfer work stations as a unit. The other tree secures the remaining magazines as a cluster for handling within and between the airlock and the fixed airlock shroud work station. These magazines are attached directly to the boom hook and transferred individually to the center work station while the tree remains in its receptacle.

Two "clothesline" film transfer units are available in stowage containers on the sides of the boom housings as a backup to a spare boom and for normal film retrieval on the last extravehicular activity of the mission. These are endless lines with hooks for attachment to special brackets located at the fixed airlock shroud, center, and Sun-end work stations. The lines are manually deployed and the film magazines are secured with tether hooks. Two spring-loaded clamps adjacent to the hatch are provided for managing the crewman's life support umbilical. After egress from the lock compartment, each crewman inserts his umbilical into the clamp with predetermined amounts of slack, depending on the activity to be performed. In the event of side loads, the spring-loaded jaw will release, thus preventing possible damage to the umbilical. A locking stowage hook is provided for temporary restraint of loose equipment.

The film transfer booms and control panel operated flawlessly during operations at the fixed airlock shroud work station, except during the second activity by the first crew. After one boom was extended the first time, the retract switch had to be cycled once to make the boom retract. This did not recur, and no other problems were experienced with the boom, control panel, or boom hooks. During the third extravehicular activity of the second manned period, however, scratch

marks were noticed on the boom's tubular element. The booms were effective methods of translating massive equipment in space. The boom hooks were adequate to secure the film tree and magazines and hold them in the proper orientation. Figure 10-50 is a photograph showing retrieval of the film tree with two film magazine con-

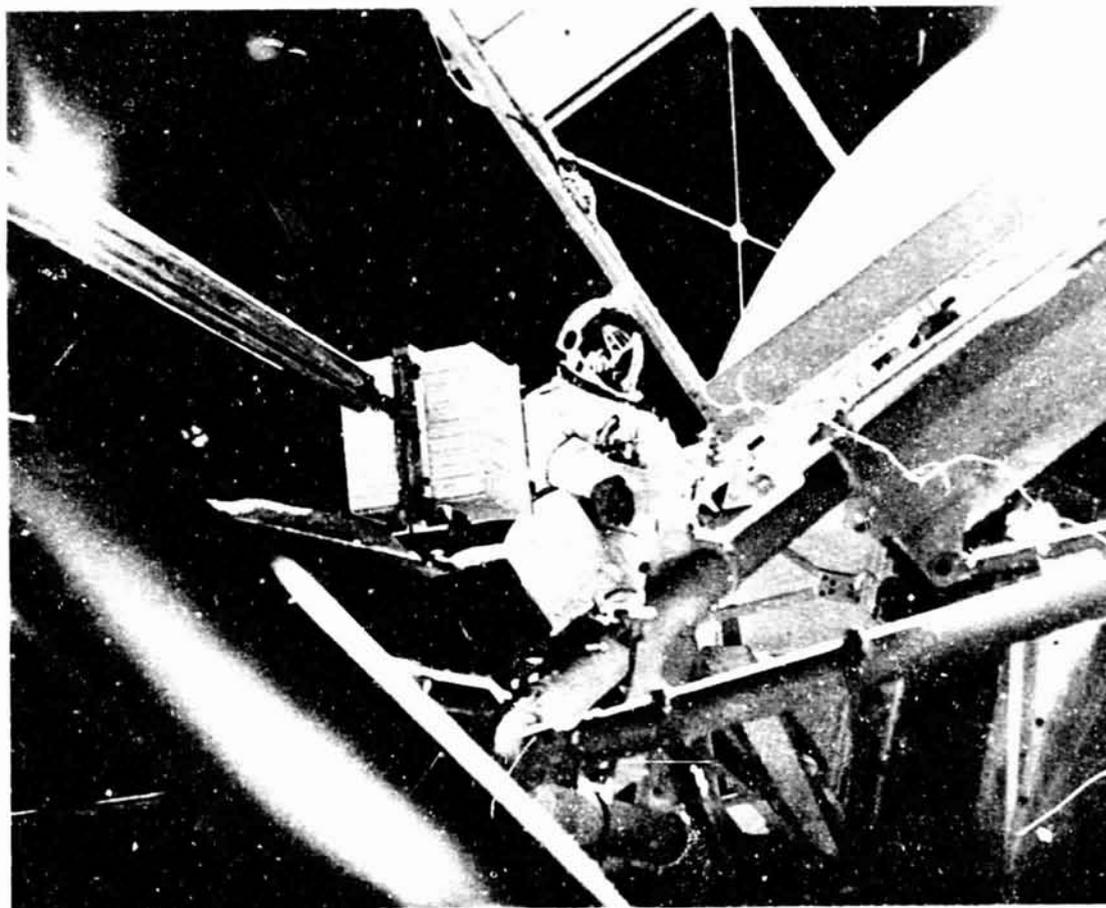


Figure 10-50.- Solar observatory film retrieval.

tainers attached, using the film transfer boom and boom hook. The film trees worked satisfactorily and no problems were encountered with the tree receptacles. The film trees were convenient for transporting several pieces of equipment simultaneously. The clotheslines tended to get tangled and took some time to straighten out, and the third crew had to be careful when entering the hatch to prevent getting their umbilicals entangled in the deployed clothesline. The life support umbilical clamps operated satisfactorily and were easier to use than they had been in the neutral buoyancy trainer. All handrails were adequate for crew stability and translation. The foot restraints provided adequate crew restraint when used in combination with a handhold or handrail, and illumination levels were sufficient for all film retrieval activities.

During some extravehicular activities a data acquisition camera and universal mount were used to photograph selected events at the other work stations. Several of the airlock shroud handrails were marked with aluminum tape to identify camera mounting locations. These were used during operations with both the film camera and a video camera. The cameras were difficult to mount, point, and operate; special firm mounting brackets should have been provided for this purpose and located to minimize accidental contact by a crewman.

Solar Observatory Center Work Station.- This work station is located to provide access to the cameras inside of the experiment canister. The crew equipment for film magazine removal and replacement includes a canister rotation control panel, experiment access doors, film magazines and receptacles, a protective screen, lights, handrails, a foot restraint, and a life support umbilical clamp. The rotation control panel provides a means for rotating the experiment canister to position each of the camera access doors at the center and Sun-end work stations. A hand controller allows two speeds in each rotation direction and can be operated with the pressure suit gloved hand. A protective screen made from perforated sheet aluminum prevents contact between the crewman's legs or feet and the solar observatory gimbal rings or canister launch lock arms during canister rotation. The four manually operated doors in the side of the canister for film retrieval are discussed in 4.2.2. The film magazines for four experiments are installed at the center work station. Each can be mounted into the canister receptacle with one hand and incorporates visual and tactile indication of position and locking status. Alignment stripes, flags, positive detents, and end-of-travel stops are used in various combinations. The receptacles include entry guides to provide self-alignment, thus reducing the requirement for fine alignment by the crewman and preventing contact with delicate portions of the experiment. Lights, handrails, foot restraints, and the umbilical clamp are similar to those at the fixed airlock shroud. A clothesline bracket with a temporary stowage hook is mounted on a boom to the right of the work station. The crewman can manually deploy the bracket to any one of three positions.

The rotation control panel operated satisfactorily during all film retrieval activities. The protective screen kept the crewman away from the moving canister equipment with no interference or significant loss of mobility for film retrieval. A hinged or removable screen, however, would have been preferable for performance of contingency repairs or service on experiment hardware, such as the filter wheel manual positioning. All film access doors operated as expected with one exception (4.2.2). No problems occurred installing the film magazines in the experiment receptacles or removing them after the film was used. Usefulness and operation of the other work station equipment was adequate for all film retrieval activities.

Solar Observatory Sun-End and Transfer Work Stations.- Removal and replacement of two film magazines is accomplished at the Sun-end of the experiment canister. Access doors, film magazines and receptacles, temporary stowage containers, a clothesline bracket, handrails, lights, and a foot restraint platform are provided for this task. Since the Sun-end work station is around the corner from the airlock shroud work station and therefore inaccessible to the film transfer boom, the transfer work station bridges this gap and provides a position for removing the film magazines from the boom. Except for a standard foot restraint, the transfer work station contains no separate crew equipment. A crewman at the transfer work station removes the loaded film tree from the boom and places the tree in a receptacle on the sunshield for access at the Sun-end work station. The work station is also used for deployment of the clothesline and clothesline bracket for film retrieval. The two film retrieval access doors (fig. 4-10) can be opened with one gloved hand by rotating a handle with a mushroom-shaped pushbutton lock. Friction hinges hold the doors open at any desired point. The experiment aperture doors, which cover the access doors in their closed position, are opened from the canister rotation control panel. The film magazines are inserted into the canister receptacles with one hand, and each magazine uses flag indicators, detents, and stops for position and locking status. Alignment arrows and insertion guides eliminate fine positioning requirements for the crew. A box-like temporary stowage container, with four flexible retaining flaps, secures

the unexposed film magazines while the exposed magazines are removed from the canister receptacles and placed in the magazine containers. The film magazines are mounted in the containers for protection from thermal effects and contamination. The containers are secured to the film tree, which attaches to the film transfer boom hook (fig. 10-50). The film tree is temporarily stowed in a receptacle identical to the one at the fixed airlock shroud work station. The clothesline attach bracket is a two-part folding boom mounted on the sunshield. The boom is unlocked by releasing a ball-lock pin and swung into position where latches hold it in place. Lights, handrails, and foot restraints are similar to those at the fixed airlock shroud work station.

One experiment door was difficult to open during the second manned period, and the crewman had to put both knees on the canister surface and pull the handle with both arms to open it. The film magazines, receptacles, and containers all performed satisfactorily, and lighting and restraint provisions were adequate. The clothesline boom was used to support the clothesline during the last extravehicular activity. The only problem noted was difficulty in releasing the ball-lock pin during deployment.

## SECTION 11 CONTAMINATION

The effects of the external Skylab-induced atmosphere on the Saturn Workshop optics and coatings, as well as the effect of the internal atmosphere on optics, are described in this section. This mission was the first long-duration exposure of a manned spacecraft to space environment, and thus provided new contamination information.

The ambient atmosphere had little effect compared to that induced by the spacecraft itself. Heavy emphasis was placed on premission design and operational planning to minimize the level of spacecraft-induced contamination. Several contamination measurement instruments and experiments were flown for objective evaluation of the atmosphere and contaminant deposition, and math models also were used to provide contamination predictions. The math model predictions were updated and validated throughout the mission as specific data became available from measurements and crew observations.

Section 12 describes the contamination experiments and other referenced experiments, and information pertaining to control of internal contamination can be found in 10.1.7. Detailed contamination results are contained in reference 12.

### 11.1 INDUCED ATMOSPHERE

The atmosphere surrounding Skylab is composed of the Earth atmosphere at that orbital altitude and the molecular material and particles emitted by the vehicle. The ambient atmosphere at an altitude of 435 kilometers consists primarily of atomic and molecular oxygen and molecular nitrogen, with an average density of  $4 \times 10^{-15}$  g/cm<sup>3</sup>, which has a negligible effect on Saturn Workshop operations. The major sources of the artificial or induced atmosphere are outgassing of nonmetallic materials, venting of liquids and gases, leakage of cabin atmosphere, motor exhaust products, and matter emitted from pressure suits or scuffed loose during crew extravehicular activities. These materials consist mostly of high-molecular-weight outgassing products and low-molecular-weight gases such as hydrogen, nitrogen, oxygen, carbon dioxide, and water vapor. The atmosphere may also include particles in the form of ice crystals that result from liquid dumps or from nucleation of water vapor or other vented gases, and loose material sloughed from Skylab surfaces.

The amount of contamination entering the atmosphere because of outgassing is determined by the area exposed to the vacuum, the surface temperature, and the type of material exposed. The total Skylab nonmetallic area exposed to the vacuum of space is approximately 250,000 ft<sup>2</sup>. The average steady state outgassing rate predicted for Skylab was 200 g/day, assuming an average rate of  $10^{-11}$  g/cm<sup>2</sup>-sec. There are approximately 200 different nonmetallic, vacuum-exposed materials with surface areas larger than 1 ft<sup>2</sup> on Skylab. The major nonmetallic materials having high outgassing rates are the various paints and coatings



Table 11-1.- Skylab Vent Characteristics

Module and vent	Frequency of operation	Constituents
<u>Command and service module</u>		
Steam vent*	Unscheduled	Water vapor
Urine vent*	Unscheduled	Fecal bag gas, oxygen, frozen urine, urine vapor
Auxiliary urine vent*	Unscheduled	Fecal bag gas, oxygen, frozen urine, urine vapor
Waste water vent*	Unscheduled	Ice, water vapor, hydrogen, potassium hydroxide
Air vent	Continuous	Silicone rubber and sealants, silica fiber
Hydrogen and oxygen purge vent	Periodic--first 13 days	Hydrogen, oxygen, nitrogen, potassium hydroxide, water
Fuel cell hydrogen cryogenic dump	Unscheduled	Liquid hydrogen
Fuel cell oxygen cryogenic dump	Unscheduled	Liquid oxygen
Fuel cell hydrogen cryogenic relief	Unscheduled	Hydrogen
Fuel cell oxygen cryogenic relief	Unscheduled	Oxygen
*Not used while docked		
<u>Docking adapter</u>		
Vacuum vent	Once--during launch	Nitrogen
Experiment vent	Each experiment cycle	Scattered metals, metal vapors, particles, exothermic gases
<u>Instrument unit</u>		
Sublimator vent	Once--start of mission	Water vapor
<u>Airlock</u>		
Molecular sieve vent (2)	Continuous	Carbon dioxide, water, water vapor
Primary and secondary condensate vent	Unscheduled	Particles, water vapor, ice particles
Extravehicular activity depressurization vent	Once--each hatch opening	Oxygen, nitrogen
Nitrogen vent	Unscheduled	Nitrogen
Forward and aft overpressure vent	Unscheduled	Oxygen, nitrogen
Airlock overpressure vent	Unscheduled	Oxygen, nitrogen
<u>Workshop</u>		
Waste tank nonpropulsive vent (2)	Periodic--during manned periods	Oxygen, nitrogen, water, water vapor, urine, bioicide
Habitation area nonpropulsive vent (2)	Periodic--during unmanned periods	Oxygen, nitrogen
Experiment M092 and M171 vent	Each experiment cycle	Oxygen, nitrogen
Scientific airlocks (2)	Each airlock cycle	Oxygen, nitrogen
Experiment M171 vent	Each experiment cycle	Oxygen, nitrogen

composed of approximately 63 percent oxygen, 27 percent nitrogen, 7 percent carbon dioxide, and 3 percent water vapor by weight. Although the majority of the contaminants from Skylab venting and cabin leakage sources are light gases which normally do not condense on critical surfaces at exterior surface temperatures, they do contribute to the overall induced atmosphere.

Three propulsion subsystems that occasionally operate in the vicinity of the Skylab cluster emit potentially contaminating motor exhaust. These subsystems are the S-II stage retrorockets; the service module reaction control system, which operates during command and service module maneuvers; and the Saturn Workshop thruster attitude control system, which operates intermittently during the mission.

The four retrorocket engines used to separate the launch vehicle S-II stage from the Saturn Workshop are located on the forward end of the S-II stage. During the 1.9-second firing time for separation, each engine expels 188 pounds of exhaust material. Since this event occurs approximately 5.5 minutes before jettisoning the shroud, the impingement on critical surfaces is minimal and is not considered a problem.

The service module has four clusters of attitude control engines, each of which contains four engines. Figure 11-1 shows the engine orientation relative to the Saturn Workshop coordinate axes. The engines are used to control orientation of the craft during flyaround inspections, trim maneuvers to adjust the orbit, rendezvous, and docking and undocking maneuvers, and for contingency attitude control of the Saturn Workshop. The primary engine exhaust products are shown in table 11-II.

The Saturn Workshop thruster attitude control subsystem is a cold nitrogen gas system which has one set of three thruster nozzles located on the +Z axis and another set on the -Z axis at the aft end of the workshop. Each set contains one thruster directed parallel to the Z axis and one each directed along the +Y and -Y axes. This subsystem is used as needed to augment the control

Table 11-II.- Service Module Reaction Control System  
Engine Products

Product	Weight percent	Product	Weight percent
H <sub>2</sub>	41.98	H <sub>2</sub>	0.65
H <sub>2</sub> O	30.65	O	0.63
CO <sub>2</sub>	9.83	H	0.1072
OH	3.47	HCO	0.0013
O <sub>2</sub>	2.57	NH	0.0007
NO	1.39	N	0.0006
Trace metals, unburned fuel, and oxidizer	Approximately 9.32		

moment gyros during orientation maneuvers and during stabilization activities. The thrusters produce a visible plume of condensed and frozen nitrogen particles. However, the clearing times of the plumes are quite short, as they dissipate approximately 30 seconds after thruster shutdown. Moreover, the thrusters are seldom used during data acquisition.

The crewmen perform tasks outside of the Saturn Workshop to tend experiments and make repairs. While outside, the crewman's pressure suit can become a local source of contamination by venting particles of water and molecular matter such as oxygen and carbon dioxide. These contaminants are emitted from ports on the front of the pressure control unit, which is worn on the crewman's chest. The normal direction of the exhaust flow is directly toward vehicle surfaces. Impingement of the contaminants on surfaces is prevented by a deflector cover worn over the pressure control unit to change the direction of this flow while the crewman is working near susceptible surfaces. This is shown in figure 11-2.

In addition to the recognized sources of contaminants, random particles are added to the induced atmosphere from unpredictable events. These include blistering and flaking of painted surfaces, loosening of launch debris, expulsion of residual solid debris from thrusters, and other debris working their way loose from the Saturn Workshop. The loss of the meteoroid shield also exposed workshop surfaces to degradation from direct sunlight which had not been planned for, and caused flakes of paint and insulation to enter the atmosphere.

The induced atmosphere, therefore, consists of particles and molecules continuously being emitted from Skylab which form a contaminant cloud about the vehicle. The particles are slowly swept away by atmospheric drag deceleration, while the molecules are removed by intermolecular collisions with the ambient atmosphere. The generally constant introduction and concurrent removal of this matter produce a steady-state, induced environment surrounding Skylab.

The continually moving contaminants of the induced atmosphere are capable of producing light scattering and absorption problems for optical systems. As the light from an object of investigation passes through the induced molecular or particulate cloud, a portion of the signal is scattered and a portion is absorbed, resulting in signal attenuation.

The effects of light scattering on optical experiments are determined by relating the background brightness of the contaminant cloud to the light source. For any particle size distribution, wavelength of scattered light, scattering

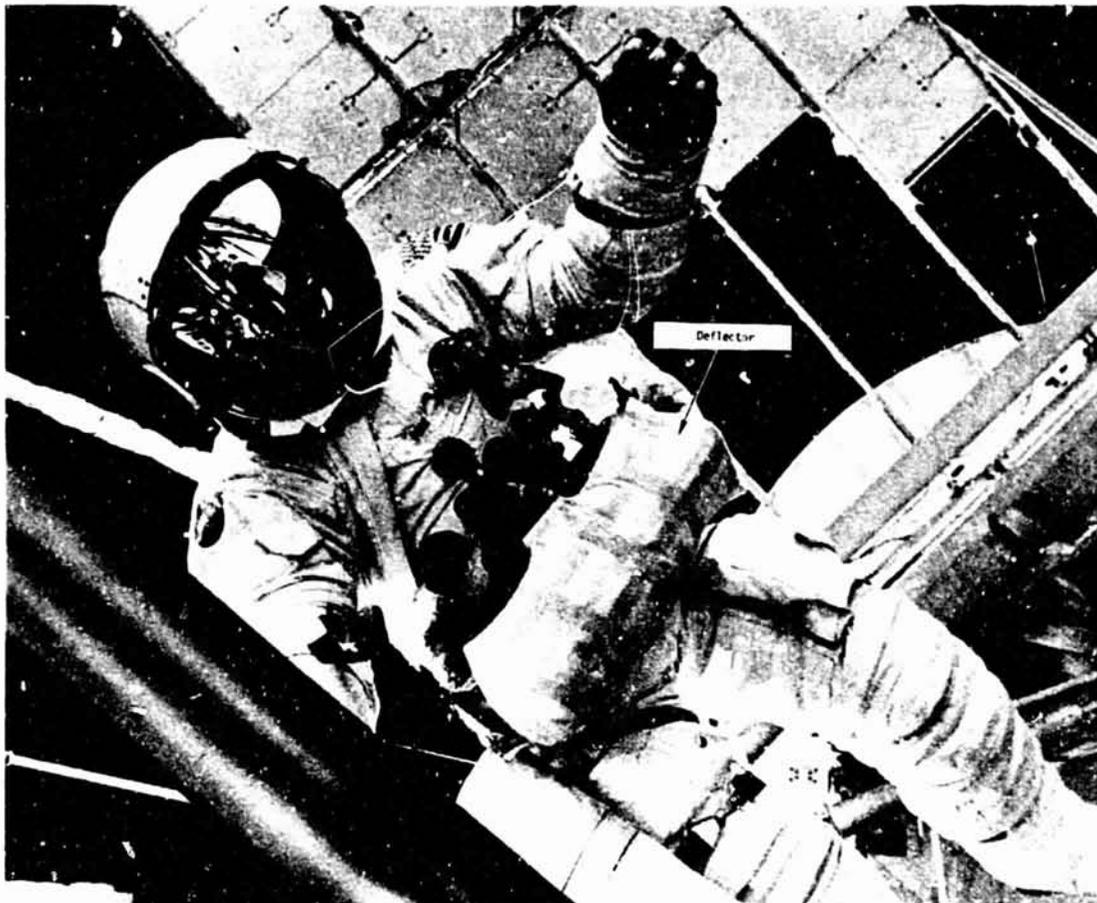


Figure 11-2.- Pressure suit exhaust deflector.

angle, and index of refraction in the induced atmosphere, a ratio of the background brightness to the source brightness ( $B/B_0$ ) can be calculated. Where the Sun is the source, this ratio is designated  $B/B_0$ . Premission scattered brightness ratio predictions for the contaminant environment produced by outgassing, leakage, and the molecular sieve and waste tank vents ranged between  $10^{-17}$  and  $10^{-15} B/B_0$ . The lowest threshold sensitivity level for any Skylab experiment was  $10^{-13} B/B_0$ . However, these predictions did not consider random sources and unscheduled venting of liquids, which, for a short period of time, could produce brightness levels exceeding experiment sensitivities.

The induced atmosphere also provides a source of contaminants which may deposit upon critical experiment or operational surfaces in the form of thin films or particulate matter. Such deposits on optical experiment surfaces cause signal attenuation by scattering or absorption, and alter the properties of thermal control surfaces.

The only materials that would be expected to accumulate on Saturn Workshop surfaces are the low-vapor-pressure, high-molecular-weight emission products. The relative temperatures of these contaminants and the surfaces determine the extent of deposition in a given area, as contaminants adhere more readily to surfaces having temperatures lower than the condensation temperatures of the contaminants.

## 11.2 OPERATIONAL CONSTRAINTS

Operational constraints imposed on venting and experiments help to minimize the effects of contamination on experiment data. These constraints either restrict venting during crucial experiment periods or avoid the collection of data during necessary venting periods. Table 11-III lists the operational venting and experiment constraints for all Skylab vents which would affect contamination-sensitive experiments and systems. The constraints were revised during the mission to provide for Comet Kohoutek observations and changes to existing experiments. Table 11-IV lists the effect of vents with constrained venting and whether the venting is scheduled or unscheduled. The Skylab vents listed in table 11-V are not under operational constraints because their operation is not directly controllable.

Table 11-III.- Operational Venting and Experiment Constraints

Vents	Star Tracker	Experiments										
		S052, S054, S055A, S056, S082A, S082B, Hydrogen alpha 1 and 2	S020, S232	S183, S019, ED23, ED26	S063	T027-S073	S073	S149 (in scientific airlock)	T025	S201	S190A, S190B	S191, S192, S193, S194, S233
Cabin atmosphere	1	1	1	2	5		5	8	1	2	1	1
Extravehicular activities (includes lock depress valve and suit overboard vent) (rule waived for S149, T025, S020, or S201 if deployed on extravehicular activity)	1	1	1	2	5		5	9	1	10	1	1
Service module reaction control system	1	1	1	2	5	1	5	9	1	5	1	1
Water dump (unbagged) into waste tank								9				
Condensate system (contingency) (begin after orbital midnight; complete before sunrise crossing or else double constraint times. If not in solar inertial attitude, vent in direction of negative velocity vector)	1	1	1	2	5		5	9	1	2	1	1
Command and service module (includes steam duct, urine dump, waste water dump, and fuel cell purges)	1	1	1	2	5		5	9	1	2	1	1
Docking adapter experiments	M479	1	1	1	2	5		5	9	1	1	1
	M551, M552, M553							9			1	1
Workshop experiments	M092			3	3		3	9		3		
	M171			1	6		1	9	10	10		
Condensate holding tank (gas side)				4	4	7	4	9		4	4	

Legend:

1. Complete venting 15 minutes before experiment exposure.
2. Complete venting 30 minutes before experiment exposure.
3. Complete overboard venting 15 minutes before experiment exposure with articulated mirror system. No constraint for venting into waste tank.
4. Complete venting 15 minutes before installation of experiment in -2 scientific airlock.
5. Complete venting 15 minutes before experiment exposure without articulated mirror system or 30 minutes with mirror.
6. Complete venting 15 minutes before experiment exposure with articulated mirror system.
7. Complete venting 15 minutes before installation of experiment. If installed, extend seven rmds and place trunnion to zero.
8. Close cassette covers during and for 15 minutes after completion of cabin atmosphere venting, or 12 hours after workshop final blowdown.
9. Close cassette covers during and for 15 minutes after completion of venting.
10. Complete venting 30 minutes before experiment exposure with articulated mirror system. No constraint for extravehicular exposure.

The effectiveness and necessity of the operational constraints were demonstrated through the mission. There were five instances where constraints were violated. During the first manned period a prolonged venting of the wardroom water purge into the waste tank occurred in which the triple point pressure may have been momentarily exceeded, a habitation area vent malfunction checkout produced particles observed by the S052 video display, and the service module reaction control engines fired while the T027-S073 photometer was deployed through the scientific airlock. During the second manned period there was a

Table 11-IV.- Effects of Vents Having Operational Constraints

Vent	Scheduled (S) or Unscheduled (U)	Effect
Service module reaction control system	S	Brief (fraction of second) increase in particulate column density; large flux of condensable materials.
Command service module vents	U	Liquid vents produce large column densities of particles, thus producing high background light scatter (particles clear within 15 minutes).
Docking adapter experiment vent	S	Debris from experiment vent can cause increased background light or cause false stars. Slight increase in molecular column densities (clearing in less than 15 minutes).
Airlock condensate system vent (contingency)	U	Particles from liquid vent can increase background brightness (clearing within 15 minutes).
Lock depress valve extra-vehicular activity	S	Increases molecular environment of docking adapter and solar observatory. No experiments operating during venting.
Water dump (unbagged) into waste tank	S	Increased molecular flow from waste tank increases column densities for scientific airlock lines-of-sight by a factor of 2 for approximately 1 hour.
Workshop experiment vacuum vent	S	Gases vented increase the molecular column densities.
Condensate holding tank (gas side) vented through -Z airlock	S	Increase molecular column densities along -Z scientific airlock lines-of-sight.
Habitation solenoid vent valve	S	Generally increases the molecular density around the spacecraft.

Table 11-V.- Vents Having No Operational Constraints

Vent	Operation description
<u>Command and service module</u> Air vent	No controls. Continuously open to vent the space between the command module meteoroid shield and pressure hull.
<u>Instrument unit</u> Sublimator vent	Uncontrolled venting (high initial flow rate of 4 lb/hr for initial 7.5 hours of first manned period) followed by continuous water vapor venting at a rate of about 0.1 lb/hr until water is exhausted (1000 hours).
<u>Airlock</u> Molecular sieve  Nitrogen vent Aft overpressure vent Forward overpressure vent Airlock overpressure vent	The molecular sieve vents are alternately operated continuous vents. Each 15-min vent cycle causes a temporary increase (approximately 2 min) in external pressure in the vicinity of the vents. Automatic regulator overpressure vent Automatic overpressure vent valve (cracking pressure approximately 6 psid). Automatic overpressure vent valve (cracking pressure approximately 6 psid). Automatic overpressure vent valve (cracking pressure approximately 6 psid).
<u>Workshop</u> Waste tank nonpropulsive vents Initial blowdown Trash airlock Fecal processor Refrigeration pump container Scientific airlock vents (blowdown) Pneumatic bottle vent	Vent valves actuate to initially depressurize the waste tank and remain latched in the open position. Each operation vents a small amount of cabin atmosphere into the waste tank with negligible effect on the nonpropulsive vent flowrate. Solids are contained by a cylindrical screen. Fecal processor operation exhausts gases into the waste tank with negligible effect on the nonpropulsive vent flowrate. Removes any refrigerant leakage from the pump with negligible effect on the nonpropulsive vent flowrate. Scientific airlock vents evacuate each experiment and the space between the experiment and the airlock before cover opening. Effluents are negligible except in the immediate vicinity; however, the venting ends before experiment deployment. Bleed down vent to empty pneumatic valve actuation supply bottle at the beginning of the first unmanned period.

contingency condensate vent during a solar observatory data collection period and a condensate holding tank gas-side vent while the S019 experiment was in the scientific airlock. Observed effects of these constraint violations are discussed in 11.4. Except for the S019 incident, there was no apparent compromise of the system or experiments involved.

### 11.3 MEASUREMENT AND EVALUATION

Before the launching of the Saturn Workshop, three computer math models had been developed to calculate Skylab surface deposition and background brightness levels. The three models were the deposition math model, the cloud math model, and the workshop waste tank math model. These programs represented the most current understanding of the phenomena of contamination. They were used for premission contamination assessment and control and for mission support. The validation of the models with flight data provided contamination information for postmission evaluation activities.

Saturn Workshop contamination detection instruments and returned photographic and experiment data were used to update the math models during the mission. This was done so that timely and meaningful contamination predictions, assessments, and evaluations could be made when specific experiments were exposed to the external environment.

The instruments that assist in determining the extent and effects of the induced atmosphere include the quartz crystal microbalances, which measure deposition; the T027-S073 photometer and the T025 coronagraph, which measure light scattering effects; and the T027 sample array, which samples and measures deposition. All of these instruments except the microbalances had been planned for use with the +Z scientific airlock, but this airlock was not available during the mission because of the thermal shield installation. A limited amount of data on deposition and the light scattering and absorption properties of the induced atmosphere was gathered by exposing the T027 sample array and the T027-S073 photometer to space through the -Z scientific airlock. Additional experiments, such as D024, S149, and S230, provided correlative data on the contaminant atmosphere.

Deposition of contaminants in selected areas of the Saturn Workshop is measured by quartz crystal microbalance assemblies. Each microbalance consists of two crystals mounted back to back. The two crystals have carefully matched thermal response characteristics to minimize the effects of temperature upon data. The forward crystal is exposed to the atmosphere and responds to any addition of mass deposited on it by a decrease in resonant frequency. The rear crystal is protected against deposition and serves as a reference crystal. The frequencies of the two crystals are compared, and the resulting beat frequency, which yields the measure of deposition for each area, is telemetered to the ground.

Two microbalances are mounted on the solar observatory sunshield (fig. 11-1) and view along the +Z axis. The crystals are slightly recessed and have a field of view of 4.14 steradians. There is no part of the Saturn Workshop in the direct field of view of these units; their primary function is to monitor the return flux of contamination molecules that could enter the solar observatory aperture doors. They monitor the effects of docking and other orbital operations on the solar experiments. Since the microbalances were first turned on 32 minutes after launch, the initial outgassing could not be seen. Consequently, the last readings before liftoff were taken as the reference. When the units first received power, they both indicated deposition of  $0.24 \mu\text{g}/\text{cm}^2$  above the reference value. This could have been due to thermal shifts, to the reference crystals' cleaning up, or to some contamination during launch. During exposure to the Sun through Day 22, these units showed a gradual loss of mass. Throughout the remainder of the

mission they did not show any indication of deposits. This was anticipated since these microbalances have no contaminant sources in their field of view and their temperatures were such that many contaminants would not deposit.

Four microbalances are mounted on a truss below the docking adapter (fig. 11-1) in the vicinity of the Earth observation experiments. These units have a field of view of 1.59 steradians. Two of these units view along the -Z direction. A third unit views along the +X axis toward the command and service module. The fourth unit views along the -X axis toward the workshop forward dome. The primary purpose of these units is to monitor the environment around the Earth observation experiments and to sense the contamination associated with docking, molecular sieve operation, and other Skylab functions.

One of the two microbalances viewing along the -Z axis operated at the ambient temperature of the truss assembly, -23 to 0°C. The other unit was insulated to retain some of its internal heat in an attempt to elevate its temperature to near that of the S190A window, which is maintained at 10°C. As in the case of the solar observatory microbalances, these units were not expected to measure any appreciable deposition, since there were no Skylab surfaces in their field of view.

Both of the microbalances viewing in the -Z direction registered deposition on the order of 10 to 24  $\mu\text{g}/\text{cm}^2$  accumulated through the mission. There is a possibility that the deposition could be attributed to reflection of outgassed material interacting with the ambient atmosphere. However, it is currently suspected to have come from a wire bundle and connector inadvertently left in the units' field of view.

Early in the first manned period the +X and -X viewing microbalances detected a sharp increase in deposition rates. This was because of multiple command and service module reaction control system firings during attempts to free the jammed solar array and to dock. No measurable amounts were recorded on the +Z or -Z viewing microbalances. The more volatile exhaust products had evaporated from the microbalances by Day 17, reducing the accumulation buildup to a more normal rate.

Again, at the beginning of the second manned period on Day 76, the +X and -X microbalances indicated noticeable increases in deposition rates. By Day 92, the deposition rates had reduced to levels comparable to those recorded before the second crew's docking. The sudden increase in deposition rates between Days 76 and 92 was attributed to the leaking oxidizer from the command and service module reaction control system.

On Day 104, the +X viewing microbalance fine voltage system electronics failed with an accumulated mass of about 36  $\mu\text{g}/\text{cm}^2$ . The coarse voltage range continued to provide measurements, but at reduced resolution. The microbalance deposition readings became unstable around Day 148, at about 42  $\mu\text{g}/\text{cm}^2$ . The instability is characteristic because as the deposited matter becomes too thick to maintain a tight bond to the crystal surface, the microbalance system tends to dampen out or fall off to saturation of its measurement range. The -X viewing microbalance reached its unstable condition at about 44  $\mu\text{g}/\text{cm}^2$ , on Day 134. Finally, by Day 182, both units reached electronic saturation at the upper limits of the measurements' dynamic range. The accumulated mass deposition measured by the +X and -X viewing microbalances through the mission was on the order of 45  $\mu\text{g}/\text{cm}^2$ .

The deposition experienced by the microbalances viewing along the X axis is believed to result from Skylab surface outgassing and the reaction control system firings. Analysis of returned experiment surfaces exposed to the external environment shows that the deposited material is primarily siliceous in nature. This material is most probably from outgassing of the silicon binder used in the white thermal control paints; however, investigations are continuing. Preflight predictions, based on data from unmanned satellites, assumed a value of 1000 hours for outgassing to reach a fraction of  $1/e$  or 36.7 percent. Microbalance data indicate that it took the outgassing on Skylab 4100 hours to reach that fraction, which reflects the long term nature of outgassing of materials.

The deposition rate measured by the X viewing microbalances and the lack of deposition rate measurement on the +Z viewing microbalances, which cannot "see" any Saturn Workshop surfaces, substantiates one of the basic assumptions of the Skylab deposition math model. This assumption is that there must be a line-of-sight between a contamination source and a receiving surface for a significant mass to be transferred to the receiving surface.

The deposition math model predictions made during the mission, with corrections for the first and second manned period docking and adjustments for configuration changes and thermal profile updates, correlated very closely with the flight data provided by the +X and -X viewing microbalances until loss of these data. The flight data from the X viewing units became erratic near Day 117. After that time, only model predictions were used to indicate deposition levels in the X axis. Figure 11-3 presents the actual accumulated deposition of the +X viewing microbalance and predicted data from the deposition math model. The -X viewing microbalance predictions and accumulated deposition are very similar; figure 11-4 shows the accumulated mass recorded by all six microbalances. The math model was also used to predict deposition on other critical Saturn Workshop surfaces. These predictions are presented in 11.4.

The light scattering and background brightness levels of the induced atmosphere cloud were first measured when the T027-S073 photometer was deployed into space from Day 29 to Day 35. Analyses of preliminary data from these measurements show that there was an induced atmosphere around Skylab greater than that calculated with the cloud model before the mission. Preflight light scattering level predictions indicated that the ratio of the brightness of the contamination background to the brightness of the Sun ( $B/B_0$ ) would be on the order of  $1 \times 10^{-17}$ . However, the photometer measurements indicated a scattered brightness ratio of  $10^{-14} B/B_0$  at a 90-degree Sun angle. Because light scattering is extremely dependent on particle size, this difference cannot be resolved until further reduction of photometer data determines the particle size and distribution.

The second T027-S073 photometer measurements were made on Day 82. This was during the period in which the +X and -X viewing microbalances measured a higher than anticipated deposition rate. The photometer readings indicated a scattered brightness ratio of approximately  $2 \times 10^{-12} B/B_0$ . These brightness level readings are considerably below the limits of the Saturn Workshop experiments except for the S073 experiment, which measures gegenschein at a ratio of  $10^{-13}$ . It was concluded that the higher brightness levels of the contaminant cloud could be attributed to the addition of the reaction control system oxidizer to the induced atmosphere, and that the static induced atmosphere scattered brightness ratio is probably  $10^{-14} B/B_0$  with small transients dependent upon operational activities.

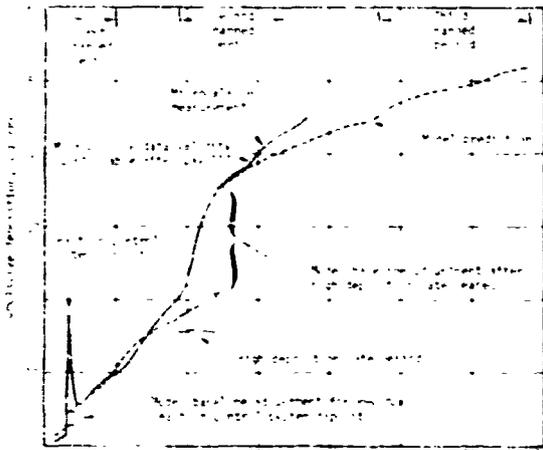


Figure 11-3.- Correlation of model predictions with +X viewing microbalance data.

brightness, the particle size was calculated from simple diffraction theory. Their sizes ranged from about 10 microns to several hundred microns. The particles all crossed the S052 television camera from the direction of the workshop, traveling toward the command and service module. However, their tracks did not appear to converge to a common location. The particles passed through the camera's field of view at angular rates ranging from 0.2 to 70 deg/sec, which correspond to velocities of 0.5 to 6 m/sec perpendicular to the camera's axis. Assuming the particles originated from the Skylab, the resultant velocity must have been greater than 1.1 m/sec. On Day 21, these particles were described as contamination balls crossing the field of view. There were times when the observation of such particles appeared to be tied to events. On Day 20, it was reported that a stream of particles was seen as the molecular sieve cycled. On Day 29, an enormous quantity of particles was observed as the habitation area solenoid vent valve was opened, venting cabin atmosphere. On Day 33, a storm of particles was reported, which may have been associated with the venting of the command and service module hydrogen tank. Additional information relating to these observations by the S052 experiment is presented in 11.4.1.

Visual observation revealed one unexpected, though not serious, source of light scattering particles: condensed nitrogen from thruster attitude control system firings. While docking the first command and service module, the crew saw a thruster plume, gray or cold blue in color, each time the workshop attitude control thrusters fired. It is estimated that the plume must have been  $10^{-7}$  B/B<sub>0</sub> to be easily

Light scattering effects of particles were observed by the solar observatory experiments. Particles were observed in the field of view of the white light coronagraph (S052) video display and were also tracked by the star tracker. These ranged from individual particles on Day 17, through particulate streams on Day 24, to "snowstorms" on Day 33.

The particles observed during the first manned period were estimated to be from 20 to 140 meters from Skylab when observed. This was determined from the degree to which the particles appeared to be out of focus. Their apparent visual magnitudes ranged from +1.8 to brighter than -5.4 because of the forward scattered light from the Sun. These correspond to star magnitudes ranging from +6 to brighter than +1. Given the distance and apparent

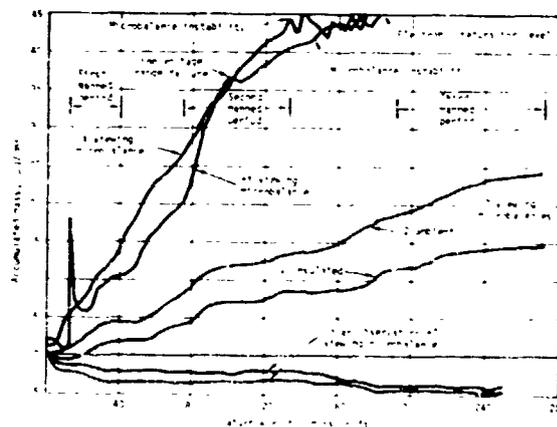


Figure 11-4.- Quartz crystal microbalance mass accumulation record.

visible. A computer analysis performed on the thrusters indicated that as much as 40 percent of the exhaust products could have condensed, and particle sizes up to 0.16 micron diameter could have resulted from homogeneous nucleation during expansion in the nozzle. A particle this size can produce scattered light which is visible with proper background contrast. The blue color indicated that the condensed particles were in the submicron range. Since this control system was never used during solar observatory or Earth observation experiments, it did not affect data from these experiments. Other experiment data taken along the affected line-of-sight were not degraded during these firings, since the plumes cleared in less than a minute.

Evaluation of data from the T027-S073 photometer, the star tracker, crew observations, and the S052 video display has resulted in certain preliminary conclusions. It is presently believed that the particles around Skylab ranged in size from 0.1 to 200 microns in diameter. The majority of particles were around 15 microns in diameter, and the fluxes of random particles were on the order of 1.3 particles per second per steradian. The induced atmosphere consists primarily of particulate matter over which no operational constraints can be exercised. Such an atmosphere will probably exist, to some degree, with any spacecraft.

#### 11.4 CONTAMINANT EFFECTS

The single most significant effect of contamination is the degradation of results of experiments that are dependent on optics. To a lesser extent, contamination may degrade the data from high energy particle collection experiments and contribute to the degraded performance of systems which are affected by external induced pressures. Contaminant deposits on optical experiment surfaces cause light attenuation by absorption or scattering or both. Noise can be introduced into optical experiment data by fluorescence, scattering, or wave front distortions. In the case of collection experiments, deposition of contaminants complicates the analysis of the collection surfaces. Additionally, the induced atmosphere may raise pressures in high voltage electrical components, leading to power losses or corona.

There are a number of optical devices and windows on Skylab which are susceptible to the contamination effects of the induced atmosphere. The optics in the solar observatory and the Earth observation sensors are susceptible to both the light scattering effects of the atmosphere and deposition of its constituents. The astrophysics and engineering and technology experiments are also prone to this contamination when they are extended from the workshop through the scientific airlock. The Saturn Workshop windows are susceptible to deposited contaminants, resulting in attenuation of radiation by absorption. The star tracker optics, located on the exterior of the solar observatory, are affected by the light absorption and scattering of particles in the atmosphere. The thermal control surfaces and solar arrays can be affected by the deposition of contaminants, which would reduce thermal control and power generator efficiencies.

In general, light scattering from the induced atmosphere cloud had little or no effect upon the viewing of sensitive optical experiments. When high particle fluxes were noted, the degradation of data was momentary. Deposition of contaminants on optical surfaces, however, has probably degraded data taken by some of the experiments.

Some experiments and windows are also subject to contamination by particles inside the Saturn Workshop. An assessment of the Saturn Workshop internal environment based upon the inflight aerosol analysis experiment (T003) data indicates that the internal environment was relatively clean. The T003 particle counter measures the aerosol particulate matter concentration and distribution in the 1 to 100 micron size range. The collected particles were returned to Earth for analysis. The particle count was on the order of 3000/ft<sup>3</sup>. For comparison, the particle count in a typical office environment is approximately 500,000/ft<sup>3</sup>.

#### 11.4.1 Solar Observatory Experiments

The solar physics experiments contained in the solar observatory include the white light coronagraph (S052), the X-ray spectrographic telescope (S054), the ultraviolet scanning polychromator spectroheliometer (S055), the X-ray telescope (S056), the extreme ultraviolet spectrograph and spectroheliograph (S082A and S082B), and the hydrogen alpha telescopes. All the optics in the solar observatory have aperture doors which are closed during nonoperational periods to protect the optics from external contaminants and thermal degradation. The two quartz crystal microbalances mounted on the solar observatory sunshield have a larger view angle than the experiments. Therefore, the presence of contaminants from external sources would be detected before the experiments could be affected. Since there are no surfaces in the field of view of the optics, the main source of deposits would be from inside the solar observatory canister.

During the process of obtaining television images of the Sun, numerous particles were observed in the S052 field of view beginning on Day 17. The most clear-cut particle sighting correlation during the first manned period was the appearance of particles on Day 29 during the malfunction checkout of workshop habitation area vents. The crew's comment as they opened the vent valve was, "looks like the 4th of July on the white light coronagraph." During the extravehicular film retrieval on Day 37, the S052 occulting disk was "dusted" with a camel hair optical brush, removing what appeared to be a small piece of white thread. During this extravehicular activity, a single piece of aluminized mylar, a loose washer, and blind rivets were also observed floating out of the canister. During the second manned period, a large shower of particles occurred on Day 87, which correlated with a condensate system malfunction checkout. Liquid from the condensate tank had been vented through the contingency condensate system vent while an S052 experiment was being conducted. A temporary degradation of experiment data resulted from light scattering effects during the particle shower. During the extravehicular activity for film retrieval on Day 132, the S052 occulting disk was again dusted to remove what appeared to be a small metallic whisker. These instances were isolated and did not cause a contamination problem with the solar physics experiments. Many S052 video transmissions showed no particles present in the field of view, indicating that particles are not a continuous phenomenon. There is no evidence that external contamination significantly degraded S052 experiment data.

On Day 25 the S054 door was latched in the open position because of door operating problems. It was determined that the risk of data loss due to contamination from an external source was less than the risk of data loss due to a stuck door. This was based upon microbalance data which indicated that there was no deposition of contaminants on the Sun end of the solar observatory. In addition, the structural partitions and layers of superinsulation between the

experiments minimized the potential effects on other experiments from external contamination entering this door. Subsequently, the doors for the hydrogen alpha 2, S082A, and S082B experiments were either latched or inhibited in the open position because of door problems. Leaving the doors open did not contribute to degradation of the experiment data. The solar observatory canister internal pressure and temperature measurements were monitored during the mission to assess the possibility of deposition on optics from outgassing, and no deposition effects were noted.

#### 11.4.2 Earth Observation Experiments

The Earth observation experiments include the multispectral photographic facility experiment (S190A), the infrared spectrometer experiment (S191), the multispectral scanner experiment (S192), the microwave radiometer, scatterometer, and altimeter experiment (S193), and the L-band microwave radiometer experiment (S194).

The docking adapter window, through which the internal S190A cameras collect data, has an external cover which can be closed to limit the deposition of contaminants on the optical surface. The S191 and S192 experiments have external aperture doors to protect the optics from contaminants and thermal degradation. These covers remain closed except during data collection periods.

The crew observed particles through the S190A window while opening the window cover on Day 27. These particles were apparently paint chips caused by the window cover's contacting the external docking adapter surface. The particles were not numerous and did not noticeably affect data. Also, on Day 28, the thruster attitude control system fired approximately nine times during data taking. However, the Earth observation film condition and scientific content were good.

On Day 16, the crew observed brownish spots on the internal S190A optical filters, but did not clean the filters at that time. These spots may have been residue from condensation. The S190A desiccants were also observed to be white, indicating moisture had been present in or around the camera. During the second manned period, the desiccants were inspected and found to be pale purple rather than blue in appearance, indicating possible saturation. Desiccants were subsequently changed at intervals of 2 or 3 days. No condensation was noted on optical elements. On Day 27, the crew observed specks of dust or bubbles on the interior surfaces of the lenses of all camera channels. Using a penlight, the crew inspected the lenses on four of the camera stations on Day 126 and again observed fine particles or imperfections on inner lens elements near the camera shutters. The origin of the particles was definitely internal to the camera and the surfaces were not accessible for cleaning. Scattering of light from these particles adds to, and probably masks, scattering effects from other contamination sources. All three crews observed emulsion streaks on the film platens and were successful in removing them and cleaning the platens. However, some minute areas of photographed ground scenes were obscured. This was apparently due to the presence of dust and possibly a slight amount of other material on the platens. This condition has had no substantive degrading effect on the data.

To preclude failure of the S191 aperture door in a closed position, it was left open from Day 91 until Day 131. The microbalances recorded an increased

contamination environment just before the door-closing difficulties. There is a possibility that the service module oxidizer leak contributed to the problem by oxidizing the lubricant on the door hinge. Preliminary review of the S191 data taken during the first manned period indicates the possibility of some deposition on the external optics because of the reflection of outgassants by the ambient atmosphere. Until further data reduction is completed, no contamination-related conclusions can be made.

The S192 aperture door was inadvertently left open between Days 96 and 98, more than doubling the exposure of the S192 optics to the external environment. Since the optics were well protected from line-of-sight contamination sources, even with the door open, detectable contamination effects were not expected. No evidence of S192 experiment data degradation has been found.

The operation of the S193 experiment was normal until Day 125, when the crew observed antenna pitch and yaw control difficulties. The malfunction appeared to be electrical and possibly the result of short circuits by scraps of aluminumized insulation on the antenna position feedback potentiometers, which are mounted on the antenna's gimbal structure. Extravehicular repair was considered feasible, and on Day 193 the crew inspected the antenna, performed electrical tests, and removed some foreign material in the gimbal area. The crew was able to restore controlled motion of the antenna in the yaw direction, but had to disable the pitch gimbal motor and pin the pitch gimbal at a zero degree pitch angle. There were no indications of contamination effects on the S193 experiment data. Radiometer and scatterometer return was as predicted. The tunnel diode amplifier bias, which is indicative of degradation of the receiving crystal, was within tolerances. It was calculated that there was approximately  $2.5 \mu\text{g}/\text{cm}^2$  of accumulated deposition at the antenna feedhorn, which was far below experiment tolerance. Figure 11-5 illustrates the estimated accumulation computed through use of the deposition math model. The pressures around S193 were calculated to be on the order of  $1 \times 10^{-6}$  torr, which is approximately three orders of magnitude below corona onset values.

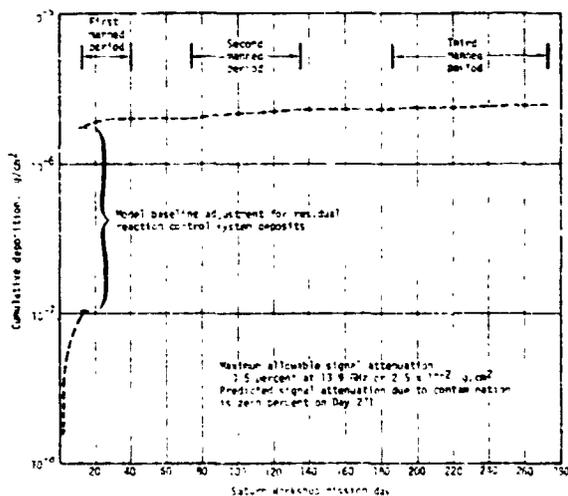


Figure 11-5.- S193 Feedhorn deposition model predictions.

ultraviolet electronographic camera experiment (S201), two contamination measurement experiments (T025 and T027), the particle collection experiment (S149), and

The S194 antenna was exposed to the intermittent firings of the service module reaction control system throughout the mission as well as the leaking oxidizer during the second manned period. These occurrences could have resulted in deposition or oxidation of S194 surfaces. To date, no contamination effects on S194 data have been noted.

#### 11.4.3 Scientific Airlock Experiments

The experiments operated in the workshop scientific airlock include the ultraviolet stellar astronomy experiment (S019), the ultraviolet airglow horizon photography experiment (S063), the gegenschein and zodiacal light experiment (S073), the ultraviolet panorama experiment (S183), the

the Earth terrain camera (S190B). The S149 and S201 experiments were also performed from locations outside of the workshop and are discussed further in 11.4.4.

During the first and second manned periods, a series of incidents involving S019 experiment systems occurred which may have resulted in some experiment data degradation. Since the S063, S073, S183, and S201 experiments used S019 hardware components, their data may also have been affected.

On Day 17, the articulated mirror system tilt and rotation control malfunctioned. The crew performed maintenance on the system for approximately an hour, during which time the mirror surface was exposed to cabin atmosphere and crew breath. In addition, a smudge or fingerprint was discovered on the mirror surface. This was not removed, as the probable effect on experiment data was considered to be slight. Data collected by the second crew on Days 95 and 96 may have been influenced by condensation or particles from an evacuation of the gas side of the condensate holding tank through the scientific airlock vent which occurred in violation of operational constraints. On Day 99, the articulated mirror system would not retract and remained in the scientific airlock for approximately 28 hours until it was successfully retracted. During this period the mirror reached a temperature calculated to be approximately  $-30^{\circ}\text{C}$ . Upon removal into the workshop, droplets of moisture condensed on the mirror surface, further contaminating it. Subsequent inspections and photographs revealed some scratches, abrasions, and apparent contamination particles.

There is a strong possibility that contamination deposits on the mirror degraded the S019 data from the second manned period. Analysis of the data indicated that the signal intensity received from a specific star field in the 1500-angstrom spectral region, when measured during the second manned period, had degraded approximately 50 percent as compared to a measurement of the same star field at the start of the first manned period. Because of this deterioration in ultraviolet reflectivity and plans for extensive use of the mirror, a replacement mirror was installed by the third crew. Preliminary review of S019 data from the third manned period shows no obvious effects due to contamination. Since no known anomalies related to the replacement mirror occurred, no degradation is expected in data taken with this mirror.

The S063 experiment operations began during the second manned period. Photographic data taken through the wardroom window and airlock windows 3 and 4 may have been degraded by contamination of the windows. The nature of this contamination is discussed in 11.4.5. The S019 articulated mirror system was also used in obtaining S063 data, so it is possible that degradation occurred because of the reduced ultraviolet reflectivity of the mirror. To date, however, no serious degradation to the data has been found.

During one S183 experiment data collection period on Day 21, the crew reported seeing a few particles on the solar side when using the S052 white light coronagraph video display. The moon was almost full and reflected moonlight from the gold surface of the workshop could have affected the S183 spectra and been interpreted as a contamination scattering phenomenon. While these conditions were not desirable for acquisition of S183 data, they did not seriously affect the data. One frame of S183 photography, taken on Day 37, shows a tumbling object moving across the field of view. Examination of conditions existing at the time

seems to rule out the possibility of the object being particulate matter near the workshop. The object appeared to blink every 5 seconds, which may indicate that it was a tumbling shroud segment or other large piece of debris some distance away. Since the S183 experiment also used the S019 articulated mirror system, the data collected will have to be analyzed to determine if the mirror surface contamination caused any degradation. Experiment operations conducted during the third manned period with the new mirror revealed no effects due to contamination.

The S201 experiment film indicated corona problems during approximately 25 percent of the camera's operation through the -Z scientific airlock. The hardware to attach S019 and S063 equipment for use in the airlock could have increased the instrument's leakage rate. This would cause the higher pressures which allowed corona to occur. No corona problems were observed during extravehicular activity operation of the camera, which tends to confirm the possibility of leakage during the airlock operations. The S201 experiment also used the S019 articulating mirror for the airlock exposures, and some data may be degraded because of the reduced ultraviolet reflectivity of the mirror.

The T027 sample array was deployed through the -Z scientific airlock on Day 35 and retracted on Day 37. The upper carousel did not close properly, so the cold upper carousel samples were exposed to cabin air, with condensation very likely occurring. Laboratory analysis of the returned samples indicates deposition levels below  $10^{-7}$  g/cm<sup>2</sup> on all samples. This was the low threshold of the measurement instrumentation used and indicates close correlation with predicted values. Figure 11-6 shows the predicted deposition as computed with the deposition math model. The sample array quartz crystal microbalances could not be used since the sample array had to be operated in the -Z scientific airlock where instrumentation connections were not available.

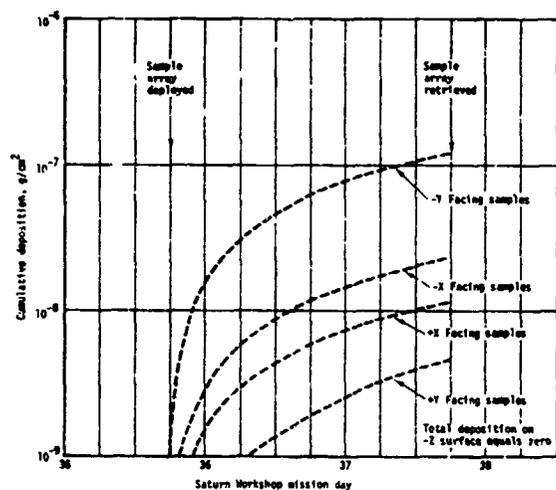


Figure 11-6.- T027 sample array deposition model predictions.

During operation of the T027-S073 photometer on Day 33, large numbers of particles were sighted on the S052 white light coronagraph video display. Exceptionally high brightness could result from light scattering by such particles. The command and service module hydrogen and oxygen vents may still have been emitting at this time since this venting started on Day 32 and continued for several days. On Day 33 the condensate holding tank (cabin air side) was evacuated through the -Z scientific airlock vacuum vent. To avoid any possible effect on the photometer, the photometer was extended and pointed directly along the -Z axis. On Day 34, the photometer was extended during the service module reaction control system trim maneuver. Because of the large distance and the fact that only the +X reaction control system thrusters fired, there was no deposition on the inside of the photometer sunshade. However, scattered light from the reaction control system plume was detectable. As measured by the T027-S073 photometer, the ratio of the brightness of the plume to the brightness of the Sun was  $4 \times 10^{-14}$ , at a 90 degree Sun angle, with possibly brighter transients. This was not bright enough nor of sufficient duration to provide serious contamination.

During the second manned period, T027-S073 photometer data were obtained only on Days 80, 81, and 82. On Day 83, after all attempts to retract the experiment equipment failed, the experiment was jettisoned, resulting in the loss of reference photographs which would have aided in the analysis of collected data. The evaluated brightness level from Day 82 data indicated a scattered brightness ratio of approximately  $2 \times 10^{-12} B/B_0$ . This level is orders of magnitude higher than that seen during the first manned period. It is presently concluded that the service module reaction control system oxidizer leak, which occurred during this data collection period, was responsible for the change in brightness levels. In general, the S073 photographic data obtained in conjunction with the photometer data were excellent. The base fog was low, with some reticulation and static discharge observed. However, the film data and scientific content were good.

Additional experiment data for S073 were obtained during the latter part of the second manned period and during the third manned period by employing the S019 articulated mirror system, the T025 canister, and the S063 camera. The evaluation of these data has not proceeded far enough to assess contamination effects. However, the information relating to contamination of these experiment optical systems will likely apply to these data also.

Because of the parasol thermal shield deployment through the +Z scientific airlock, T025 could not be operated in its normal mode. The occulting disk was moved aside and on Day 114 seven frames of excellent gegenschein photographs were taken, through the -Z scientific airlock, using S063 film. There appeared to be no degradation due to contamination, specifically that from particulate matter. However, particles in the vicinity of Skylab were not illuminated by sunlight; therefore, light scattering from the immediate vicinity of Skylab was not possible. In the third manned period, the T025 experiment was performed only to obtain visible light data from Comet Kohoutek during four extravehicular activities. Preliminary data analysis indicates that, because of a camera malfunction, photographs were made at approximately an 8-foot focus setting. Some of the frames indicate particles floating within the field of view of the instrument and may help in determining particle size or intensity data.

The S149 cassette was initially deployed on Day 38 and on Day 41 opened to space, where it remained exposed through the second unmanned period. It was closed on Day 76 and retrieved from the -Z scientific airlock on Day 79. The experiment was moved to the solar observatory sunshield during an extravehicular activity and exposed on Day 85. It was retrieved on Day 132. The S149 cassettes exhibited some oxidation and varying degrees of contamination. The cassettes exposed from the sunshield appeared to be more contaminated than those exposed through the scientific airlock. It is not known at this time whether or not contamination contributed to the formation of oxides on S149 surfaces. Contamination does not appear to have affected the S149 experiment objectives significantly.

There was no indication of contamination of any data collected with the S190B Farth terrain camera.

#### 11.4.4 Other External Experiments

Two experiments were mounted outside of the Saturn Workshop to study orbital environment and collect astrophysics data. They are the thermal control coating experiment (D024) and the magnetospheric particle composition experiment (S230).

Three experiments were deployed or operated during extravehicular activities. They were the X-ray and ultraviolet solar photography experiment (S020), the ultraviolet electronographic camera experiment (S201), and the particle collection experiment (S149).

The two sets of thermal control coatings (D024) sample trays were exposed on Day 1 when the shroud was jettisoned. The samples were continuously exposed until one set of trays was retrieved during the extravehicular activity on Day 37. When these samples were analyzed it was discovered that they were discolored a brownish yellow to brownish gold. Areas on the samples that were shaded from the Sun by nearby objects such as lanyard cables and restraining pins showed no visible discoloration. Measurements of the absorptivity of some samples indicated changes of almost an order of magnitude greater than expected. The second set of trays, retrieved on Day 132, were noticeably more degraded. Coloration over all areas exposed to the Sun was a deeper brown than seen on previous samples. Sample trays appeared darker near the edge closest to the extravehicular activity hatch, indicating that airlock or crew activity effluents may have affected the samples. The degradation in absorptivity for the white paint samples was approximately three times greater than that seen on the first samples.

Analysis of the D024 samples has been compromised by the amount of contaminants deposited on the samples' surfaces. The contaminant coating on the first set of samples measured between 700 and 2450 angstroms in thickness and was composed primarily of silicates and hydrocarbons. These contaminants could derive from materials outgassing, laboratory coolant leakage in orbit, or service module reaction control engine firings. The observed high level of discoloration was not expected and indicates a combination of contaminant deposits interacting with high energy solar radiation during the long term exposure.

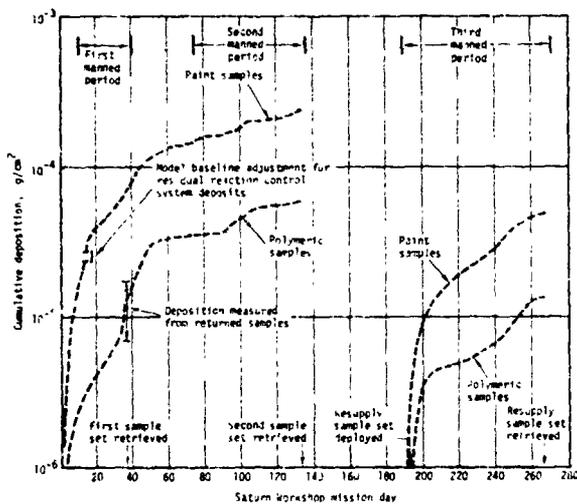


Figure 11-7.- Experiment D024 deposition model predictions.

Consequently, backup D024 samples were flown up with the third crew and exposed on Day 193. The samples were retrieved on Day 266, and exhibited contamination effects similar to those of the two previous samples. The D024 experiment was exposed to an additional source of contamination during the third manned period. On Day 226, during an extravehicular activity, a leak in the Commander's suit released large amounts of yellowish colored ice particles. A similar event occurred with the Science Pilot's suit on Day 266. In addition, the Commander's pressure control unit deflector was not used on Days 230 and 266. These events could have resulted in a significant increase in the particulate or molecular flux on D024 surfaces and increased the deposition of contaminants. Until further analysis is completed, no conclusions can be drawn from the third set of samples. Contamination thickness values calculated by the deposition math model were in close agreement with the preliminary measured values (fig. 11-7).

The S230 experiment consisted of collector foils formed into cuffs that were wrapped around two spools on the deployment assembly truss. Two cuffs were used per spool with one cuff being covered by the other. The two outer cuffs were exposed when the shroud was jettisoned and retrieved as planned on Day 85. The crew observed iridescence on the cuffs, similar to that seen on water covered by a thin film of oil. Deposition on these cuffs is suspected to be up to 1 micron thick. Only the inner cuff from the spool nearest the command module was retrieved on Day 132. It is expected to have a maximum contamination thickness of 7000 angstroms. Upon return, the two outer cuffs were visibly contaminated and were golden brown in color. If clean, they should have appeared metallic or light grey. The most deeply discolored areas were those facing away from the Sun. The inner cuff, removed on Day 132, did not appear so discolored, nor did it appear contaminated. Deposition on the collecting cuffs seriously hindered interpretation of the data.

Because of the degraded data, another inner cuff was taken up by the third crew and deployed on Day 193. This cuff and the one remaining inner cuff were retrieved on Day 266. These cuffs showed considerable deposition as well as an iridescent discoloration on the various sample strips. No conclusions relating to description or source of the contaminants can be made until the analysis is completed. The S230 experiment samples, however, were exposed to the same contamination environment as the D024 samples. Correlation between analyses of deposits on the two experiments will provide very useful information.

Because of the parasol thermal shield deployment through the +Z scientific airlock, it was not possible to operate the S020 experiment as planned. The third crew carried the appropriate hardware to mount the experiment externally for extravehicular operation. The S020 experiment was performed during three extravehicular activity periods on Days 226, 230, and 266. The first exposures, on Day 226, provided data that were good above 111 angstroms but were nonexistent below 111 angstroms. Subsequent data below 111 angstroms were exceptionally poor. Preliminary observations of the filters indicate some deposition on the surfaces. The presence of water vapor in the field of view could also have degraded the data. Further analysis will have to be performed to determine what the deposits on the filters are and how they affect the experiment data.

The S020, S201, and S149 experiments were all subjected to the suit leakage discussed previously. A significant increase in the release of particulate and molecular material in the vicinity of the experiments could contribute to degradation of the data collected.

#### 11.4.5 Windows

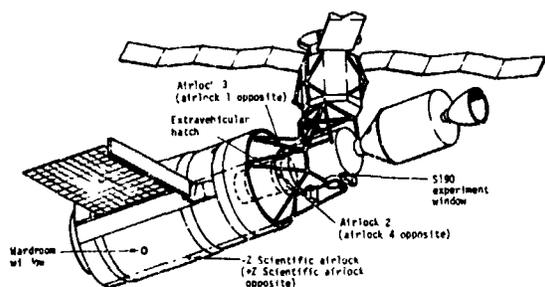


Figure 11-8.- Saturn Workshop window locations.

The Saturn Workshop has six windows used for experiment data acquisition, general viewing, and hand-held photography. Figure 11-8 shows the locations of these windows. The experiments using the windows include the ultraviolet airglow horizon photography experiment (S063), the multi-spectral photographic facility experiment (S190A), the barium plasma observations experiment (S232), the Comet Kohoutek photometric photography experiment (S233), and the Skylab-Earth laser beacon experiment (T053).

To protect the critical experiment windows, a number of precautions were taken. The S190A window contains one fixed, external, optical-quality pane and one inner, removable, lower-quality safety pane. Thermostatically controlled heating elements prevent fogging and optical distortion. The airlock windows are double-paned, sealed units. The S190A and airlock windows have hand-operated protective external covers. The wardroom window is double-paned, with provision for venting the volume between the panes. There is no external cover; however, it has both an internal protective cover and a window heater.

During the initial phase of the first manned period the S190A window heater was operated intermittently to conserve electrical power. Because of the low temperatures and high relative humidity in the docking adapter, there was the possibility that moisture might condense on the window's surface. The window heater was turned on 1 to 1.5 hours before an Earth observation experiment and turned off immediately after the pass. This heating before opening the external window cover prevented the window surface temperature from reaching the dewpoint and no condensation formed. The second crew reported cleaning two smudges from the internal surface of the window with wet wipes. The third crew, although they reported that the window was visually clean, also cleaned the inner surface. No external contamination of the window surface was observed throughout the mission. The heaters and covers for this window appeared to be quite effective in preventing condensation on the window surfaces, and there were no contamination effects on the S190A experiment.

The airlock windows were free of contamination up to Day 18, when several "leafy" particles were observed on the exterior surface of window 4. These particles were present to a lesser degree on the other windows. The source of these particles was suspected to be window frame insulation which was rubbed off by the covers during opening and closing operations. The window covers on the solar side were opened, starting on Day 19, for about 6 hours a day during the first manned period to provide additional illumination. The second crew reported that the airlock windows were left closed except for specific observations or photography. Each window was used for a maximum of about 1 hour per day, as opening the windows created light interference with solar observatory console video displays.

During the extravehicular activity to deploy the solar array wing on Day 25, a footprint was left on the outside of airlock window 2, and remained throughout the mission. Fine dust was also noted on the outside of all windows. This dust was probably tiny paint flakes scuffed loose by crewmen during extravehicular activities, as well as the particles of window insulation previously mentioned. The particles were probably attracted to the window surface and held by electrostatic charge. Airlock windows 1 and 2, opposite the solar side, showed periodic condensation on the inner surfaces when open, which cleared as soon as the covers were closed. Windows 3 and 4, on the solar side, never showed any condensation. The residue from condensation and smudges from crew contact were removed from the interior window surfaces with water and wet wipes, which was a very effective technique. Airlock window 3, which was the least contaminated of the four windows, was used to obtain S233 experiment photographs of Comet Kohoutek. Although no information on the effects of window contamination on the experiment data is available at this time, the calculated transmission loss was minimal. Figure 11-9 shows the deposition and resultant transmission loss, as calculated with the deposition math model.

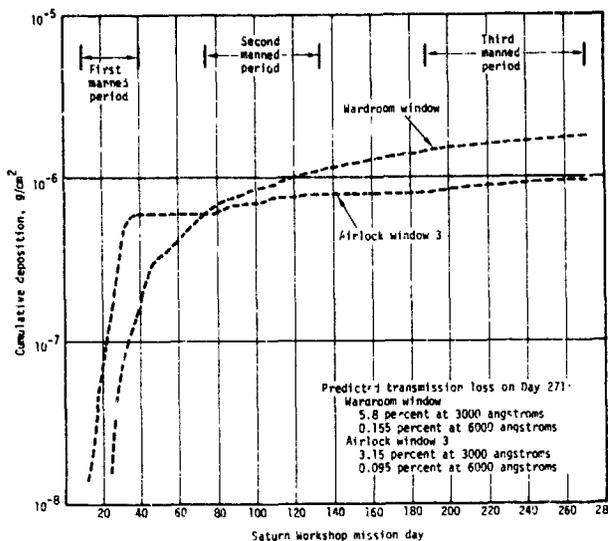


Figure 11-9.- Window deposition model predictions.

spread to nearly 4 inches in diameter. The volume between the panes was vented to space through the scientific airlock vacuum vent and then repressurized with dry air. Crew reports indicated that the vent from between the panes to the cabin apparently leaked and permitted cabin atmosphere to reenter after the evacuation process. This was evidenced by condensation streaks running from the vent orifice toward the center of the window. The evacuation and repressurization process was required approximately every 2 weeks during the second manned period and every 3 weeks thereafter, but the spot and internal streaking never completely disappeared. Even immediately after the repressurization with dry air some solid residue remained.

Television pictures taken through the window during the first manned period revealed particles which the crew reported to be the outermost surface. Those particles are suspected to have come from paint and insulation scraped loose during the meteoroid shield incident and the subsequent solar array deployment.

When the window heater was turned off, cabin atmosphere often condensed on the inner surface. The extensive use of the window for viewing also resulted in condensation on the inner surface from the crewmen's breath, along with hand and nose prints. This surface was repeatedly cleaned with wet wipes.

The usefulness of the wardroom window for photography was compromised by the contamination in the center of the window. The crew had to move around the edge of the window as close to the periphery as possible to take hand-held photographs. Figure 11-10 is a photograph of the window taken during the second manned period, showing the central ice mass, streaking from the vent, and various particles clinging to the outer surface.

Visual observation and photography were performed through the wardroom window to collect data for the S063, S232, and T053 experiments. The T053 experiment was conducted during the second and third manned periods to evaluate the use of lasers for navigation and communications. There is no indication that the contamination on the window affected the results of the T053 experiment. Analyses

The wardroom window was used extensively for general viewing, photography, and television and therefore was under continuous scrutiny. When the window was first activated, a small ice formation about the size of a dime was noticed in the center of the inner surface of the outer pane. A more critical inspection later revealed an oily film on the outer surface of the outer pane. The film appeared to have water streaks which ran toward the aft end of the vehicle. It is suspected that both of these effects resulted from conditions existing on the pad before launch.

As the mission progressed the ice spot alternately melted and refroze as the window heater was turned on and off and also as the effects of Earth albedo increased and decreased. It eventually

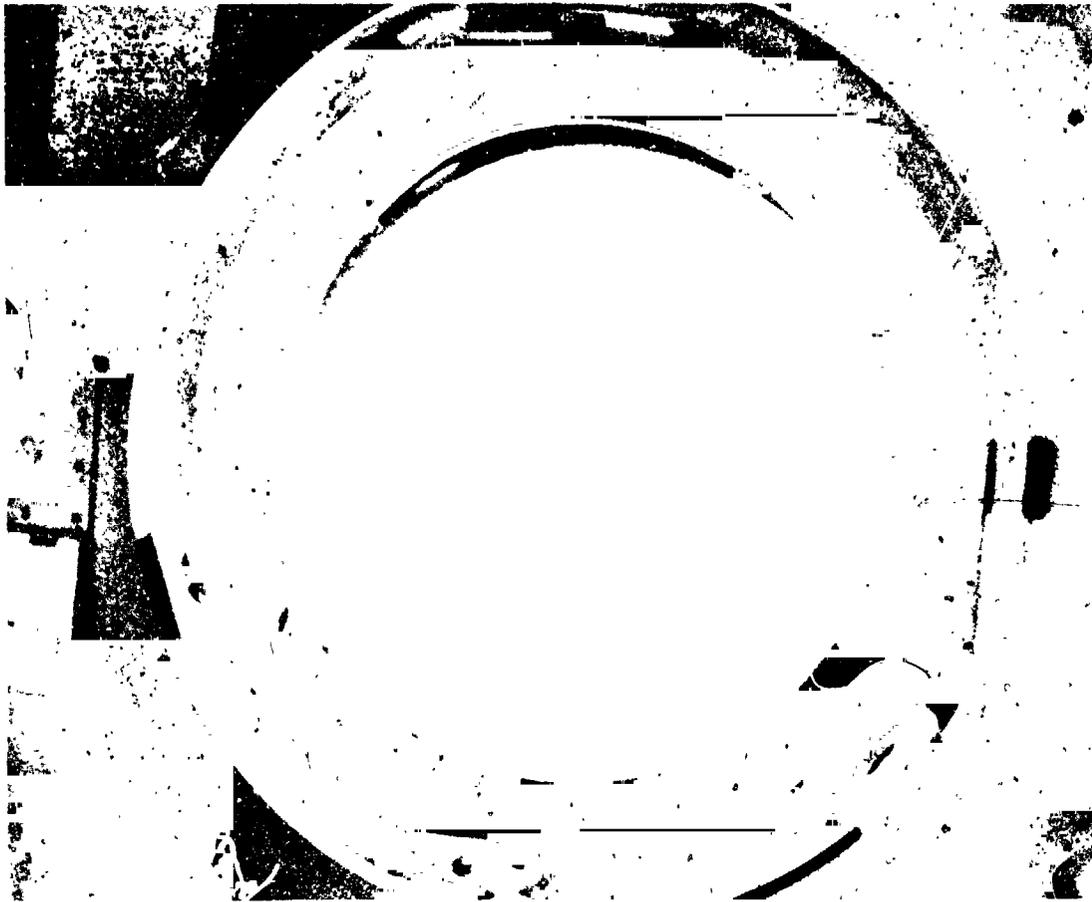


Figure 11-10.- Wardroom window contamination.

of the S063 and S212 experiment data are as yet too incomplete to assess the effects of the window contamination. As shown in figure 11-9, the deposition math model calculations revealed a loss of light transmission capability during the mission.

#### 11.4.6 Star Tracker

Contamination affects the usefulness of the star tracker when the instrument acquires, locks onto, and tracks a particle in the induced atmosphere in lieu of the star. The star tracker can abandon a target star and lock onto a contaminant particle if the particle is in the star tracker's field of view and if the apparent magnitude of the particle is brighter than the star tracker's minimum threshold. This is preset at a magnitude of 1.16, which is 0.5 magnitude below the dimmest target star. The automatic gain control in the video amplifier rejects signals generated in the star tracker phototube by objects dimmer than 1.16 magnitude. When tracking a brighter star, the automatic gain control determines a higher threshold, which decreases the possibility of acquiring contaminant particles.

During the first manned period incidents of tracking false stars were of major concern. There were far fewer incidents, however, during the second

manned period and none in the third manned period. This elimination of false tracking incidents was due to changes in star tracker operational procedures resulting from analysis of the incidents. False tracking incidents were time-correlated to potential sources of contamination to ascertain the degree to which contamination was responsible. Thirty-nine incidents could potentially be attributed to tracking of contaminant particles. Of this total, 35 were observed during the first manned period and 4 during the second manned period. Based on aerodynamic drag from the ambient atmosphere and star tracker gimbal rate evaluation, 11 of these incidents have been established as probable contaminant-particle tracking, 9 during the first manned period and 2 during the second manned period. The remaining 28 incidents could not be analyzed because of the lack of adequate star tracker tracking data.

To determine whether Saturn Workshop attitude changes rather than contaminant particles were the cause of star tracker gimbal position changes, the tracking rates of suspected particles were compared to the maximum rates attributable to various vehicle attitude changes. The majority of false stars analyzed had tracking rates from 0.09 to 0.74 deg/sec, which is characteristic of particles influenced by atmospheric drag. When compared to the maximum vehicle attitude angular rate of 0.08 deg/sec, the angular velocity in the majority of false tracking incidents was too great to have been caused by vehicle attitude changes. Thruster attitude control system firings allowed vehicle angular rates up to 0.3 deg/sec; however, these firings occurred infrequently. Only two incidents occurred during revolutions where the thruster system was used.

A number of the false tracking incidents can be attributed to the tracking of contaminant particles associated with specific Saturn Workshop events. The major source of particles seemed to be in the general area of the workshop, where blistered paint and insulation could be loosened by molecular venting, thruster firings, waste tank vent pressure flow, and vehicle vibration, or by the slower effects of the Sun, drag of the ambient atmosphere, and temperature variations. Venting of cabin atmosphere can form particles by condensation and can also transport particles already present in the flow field of the vent. This type of venting was related to incidents during M092 and M171 experiment activity. Mechanical activities such as use of the articulating mirror system, solar observatory door actuation, or installation of the S190B Earth terrain camera could also generate particles.

Figure 11-11 illustrates the track of a contaminant particle on Day 32 which lasted for 3 minutes. The suspected source of the particle was the M092 vent, from which cabin atmosphere can condense to form particles larger than 10 microns. The curvature of the track, which follows the changing aerodynamic drag vector, indicates a slow particle of small size, easily accelerated and not much larger than the minimum size detectable by the star tracker. The target star, Achernar in this case, is one of the dimmest target stars, so small particles can draw the star tracker away from it.

Star tracker operational procedures were changed twice during the second manned period to minimize the crew time lost in responding to false tracking incidents. First, on Day 87, vehicle attitude updating was inhibited except when needed. The second change, implemented on Day 106, involved closing the star tracker shutter except for the 10-second intervals needed for vehicle attitude updating. The closed shutter prevented the star tracker phototube from being exposed to any contamination or high light level sources which could

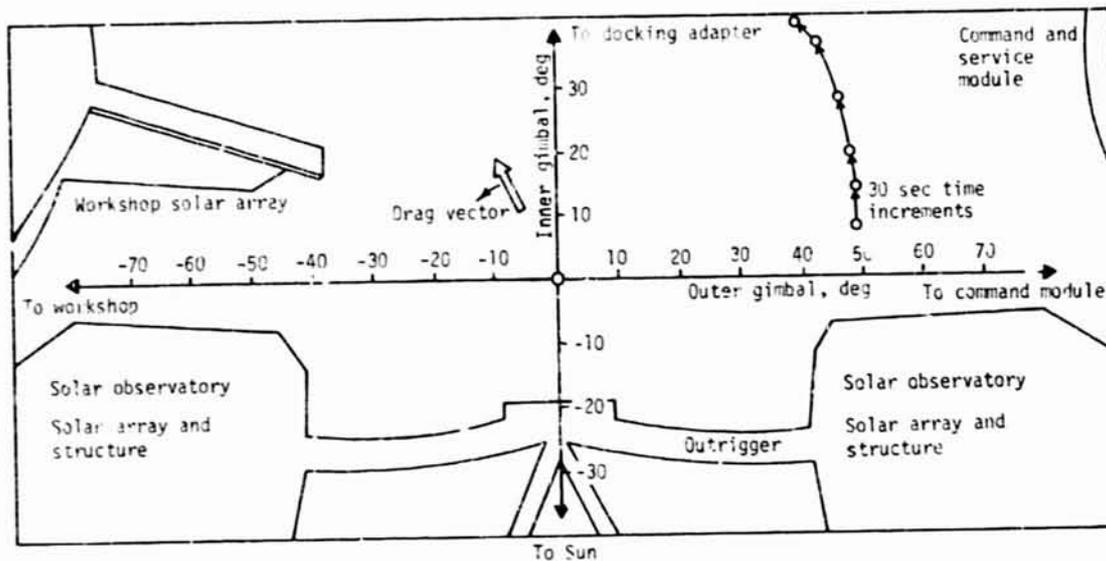


Figure 11-11.- Star tracker scanning area and contaminant particle track.

saturate the phototube. The length of time in the tracking mode was thereby reduced from approximately 12 hours a day to only minutes a day. As a result of the operational changes and the selection of brighter target stars, the false tracking incidents were all but eliminated. Only three contamination-related incidents were observed between Day 87 and Day 94. After this, no further contamination-related star tracker incidents occurred, even though particles were as frequently observed throughout the remainder of the mission.

#### 11.4.7 Thermal Control Surfaces

Saturn Workshop thermal control surfaces, such as the solar observatory, airlock radiator, and workshop aft skirt, were monitored for degradation due to contamination deposition. This was accomplished by evaluating the changes with time in solar absorptivity and infrared emissivity characteristics of the surfaces through analysis of data from selected temperature transducers. These surfaces include white coatings of zinc oxide pigments bonded with potassium silicate (Z-93) or silicone (S-13G), which were selected for low absorptivity. The command and service modules were also observed, since each one was potentially a new source of contaminants.

The thermal control surfaces apparently experienced some degradation in optical properties. Since contamination degradation is a long term trend effect, it is difficult to distinguish it from damage due to radiation. It is felt that both the S-13G paint and Z-93 coatings experienced degradation from either ultraviolet radiation or interaction between a contaminant and solar ultraviolet. Crew observations revealed that all Saturn Workshop areas exposed to the Sun turned a tan to brown color. The monitored surfaces were noticeably discolored. Command and service module surfaces exhibited a tan to brown color pattern in solar exposed areas, indicating ultraviolet degradation.

Areas of the solar observatory show definite discoloration patterns on surfaces not directly exposed to solar radiation which are, therefore, the

result of contaminant deposits. These surfaces face the extravehicular activity quadrant of the airlock from which a relatively heavy efflux of emissions occurs. Most of the outgassing and leakage from the workshop forward dome, extravehicular hatch area, forward skirt, instrument unit, and airlock is directed out this quadrant. During extravehicular activities, the airlock is vented through this quadrant and outgassing occurs from equipment located within the airlock. Photographs taken by the crews show the resulting discoloration pattern and its progressive darkening (fig. 11-12). Thermal measurements plotted during the mission indicated a gradual temperature rise in the areas exposed to these emissions. This trend was not exhibited by measurements from shaded surfaces on the opposite side of the solar observatory that do not have line-of-sight exposure to the quadrant. Thermal analyses indicate that the absorptivity changed from approximately 0.2 to between 0.47 and 0.57 by the end of the third manned period. All temperatures, however, remained well within tolerance limits.

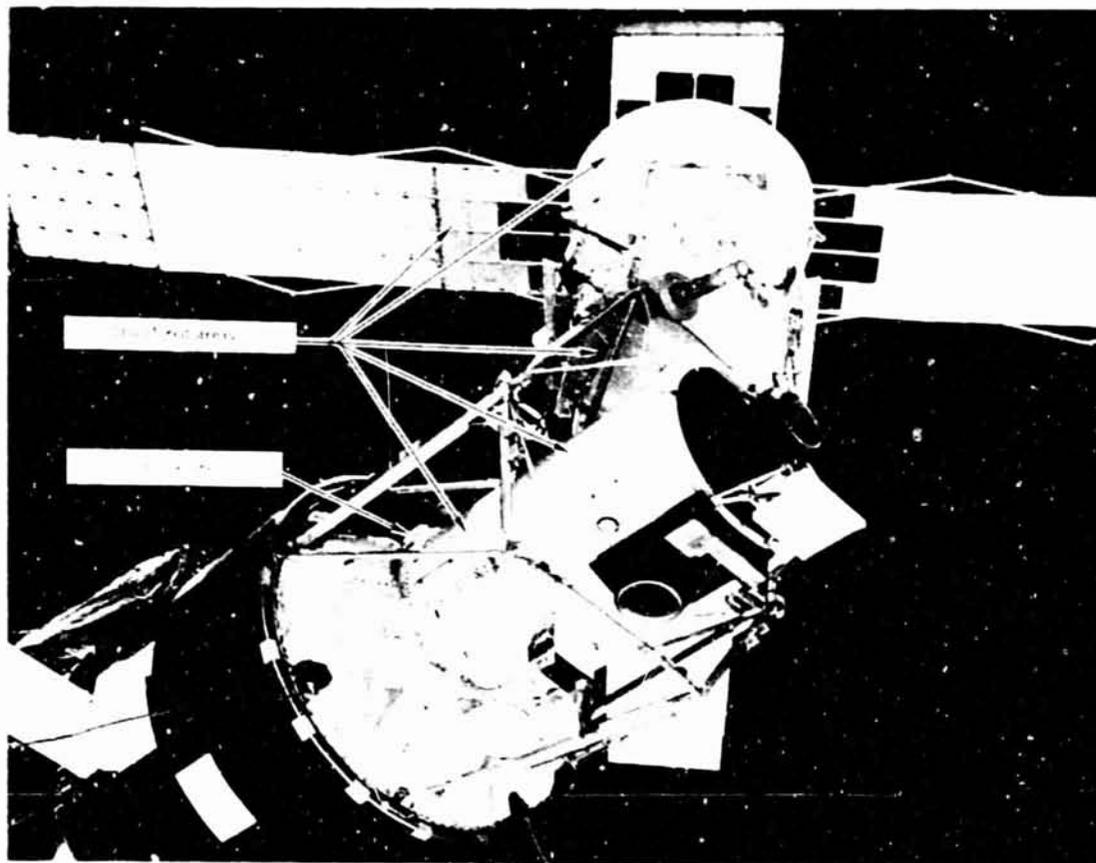


Figure 11-12.- Surface discoloration at end of second manned period.

The airlock radiator surface, located just forward of the extravehicular hatch, was expected to have higher contaminant deposition than any other Saturn Workshop thermal control surface. The Z-93 coating exposed to solar radiation and to the extravehicular activity quadrant emissions is thought to have been slightly degraded. Figure 11-13 shows that the loss of performance capability, as computed with the deposition math model, was negligible.

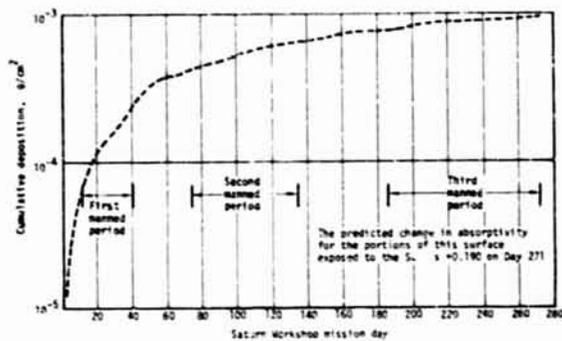


Figure 11-13.- Airlock radiator deposition model predictions.

13 showed power losses of 6, 6, and 10 percent, respectively. The exact manner and time in which the degradation occurred is unknown. Consistent solar observatory power data could not be obtained during this time period because various non-solar-inertial vehicle attitudes were required for thermal control reasons. It is suspected, however, that the degradation in the power output of these three panels resulted from physical damage from exhaust impingement during the flyaround of the first crew, since the crew has indicated that motion of the solar arrays was noticed when the +X service module reaction control thrusters were fired.

Following rendezvous and docking of the second crew, solar observatory array panels 5, 7, 10, 13, and 16 indicated temperature increases of 2 to 4°C. With the exception of panel 5, temperatures returned to a normal trend within 12 days. The temperature increase in the forward half of panel 5 was the largest, and that temperature remained higher than the others throughout the mission. The temperature increase could possibly be attributed to deposition on the backside of the solar arrays due to the oxidizer leak from the service module reaction control engine that occurred following docking. It is not known why the forward half of panel 5 did not recover as did the other panels. The aft half of panel 5 was protected from oxidizer impingement by the solar observatory and did not indicate any temperature excursions from normal. There were no significant changes noted in the power generating efficiency of the affected panels.

Flyaround photography and crew comments revealed a progressive discoloration of the thermal paint on the underside of the solar arrays closest to the airlock extravehicular quadrant, as discussed in 11.4.7.

The surviving workshop solar array sustained no detectable loss in output capability due to deposition, although predictions made with the deposition math model, using microbalance and temperature data, indicated that power losses between 2.9 and 3.4 percent could have occurred by Day 271. The crew, in their debriefing comments, indicated that they saw no surface changes on the workshop solar array that could be attributed to contamination.

Analysis of solar array systems data indicates that no major degradation of electrical power resulted from contamination. This can be attributed to the design of the electrical generating systems and the relatively high operating temperatures of the solar arrays, which discouraged collection of contaminants and caused contaminants that did come in contact with the arrays to boil off.

Detailed analysis indicates that deposition contamination did not significantly affect Saturn Workshop thermal control surfaces. The considerable deposition on D024 experiment samples will reveal the full extent of degradation from contaminants after analysis of all returned samples.

#### 11.4.8 Solar Arrays

During the time period between the first solar inertial maneuver, on Day 1, and the first solar inertial maneuver of the first manned period, on Day 14, solar observatory solar array panels 7, 8, and

## SECTION 12 EXPERIMENTS

The concept which led to the development of the Saturn Workshop originated approximately 10 years before the vehicle's flight and included limited experiments related to space engineering and man's functional capabilities. Many space payload packages were being flown on unmanned and manned vehicles during this period. All these activities served to guide the various Skylab experimenters into areas of need and feasibility. The experiment program grew as a result of the developments in other programs and as the capabilities of the evolving Saturn Workshop increased. When the "clustering" concept was introduced for the Saturn Workshop, it allowed some of the experiment packages to be docked to the "wet workshop" for resupplying, control, and other activities. Later the "dry workshop" concept carried this idea even further so that some of these packages and individual experiments could be integrated directly into the Saturn Workshop.

The mission objectives, in addition to the operation of a manned station in space for an extended period, provided for a full program of experimentation. In fact, the increase in experiment capability changed the program from a flight test of a manned laboratory to a long duration operational space mission. Table 12-1 lists the experiments that were flown. They are grouped into 8 categories and include 125 individual experiments, investigations, or demonstrations. The approved experiments were derived from several hundred candidates which either were continuations of other work underway or were new concepts. The materials science and manufacturing group and the student investigations were incorporated within the last 2 years before flight, and the science demonstrations and cometary physics experiments were developed after the mission was underway. In addition, observations from Skylab of a laser beacon at the Goddard Space Flight Center and of a barium cloud formed in the Earth's magnetosphere from a rocket launched from Alaska were also included after the mission was begun. The procedures used for reducing the candidate list over the years are presented in reference 19.

The development of approximately two-thirds of the experiments and the integration of all except five were the responsibility of the Marshall Space Flight Center. The life sciences group, Earth observation group, and some others indicated in the table were entirely the development responsibility of the Johnson Space Center, and their evaluation is not included in this report except where integration aspects are considered. Information on the Johnson Space Center experiments can be found in references 15, 16, and 17.

Development and integration of the experiments into the Saturn Workshop considered the major program objectives, compatibility with the laboratory and its resources, and the availability of crew time. Most of the experiments used the crew in varying degrees to gain the most benefit. The management procedures for developing the equipment and integrating it into the Saturn Workshop are also presented in reference 19.

Table 12-I.- Skylab Experiment Complement

Life sciences *		Astrophysics		Engineering and technology		Science demonstrations	
MD71	Mineral balance	S009	Nuclear emulsion	*D008*	Radiation in spacecraft	+S01	Gravity gradient effects
MD73	Bioassay of body fluids	*S019	Ultraviolet stellar astronomy	D024	Thermal control coatings	+S02	Magnetic torque
MD74	Specimen mass measurement	*S063	Ultraviolet airglow horizon photography	M415	Thermal control coatings (TU)	+S04	Momentum effects
MD78	Bone mineral measurement	S073	Gegenschein and zodiacal light	*M487	Habitability of crew quarters	+S05	Energy loss and angular momentum
MD92	Lower body negative pressure	*S149	Particle collection	*MS09	Astronaut maneuvering equipment	+S06	Bead chain
MD93	Vectrocardiogram	S150	Galactic X-ray mapping	*MS16*	Crew activities and maintenance	+S07	Wave transmission reflection
MI11	Cytogenic studies of the blood	S183	Ultraviolet panorama	T002	Manual navigation sightings	+S08	Wilberforce pendulum (Part I) Water drop (Part II) Fluid mechanics series
MI12	Man's immunity in vitro aspects	S228	Transuranic cosmic rays	T003	Inflight aerosol analysis	+S09 (TV107)	Fish otolith
MI13	Blood volume and red cell life span	S230	Magnetospheric particle composition	T013	Crew vehicle disturbances	+S010	Electrostatic effects
MI14	Red blood cell metabolism	S201	Cometary physics	T020	Foot-controlled maneuvering unit	+S011	Magnetic effects
MI15	Special hematologic effect	S233	Materials science and manufacturing in space	*T025	Coronagraph contamination measurements	+S012	Magnetic electrostatic effects
MI31	Human vestibular function	MS12	Materials processing in space	T027	Proton spectrometer	+S013	Airplane
MS33	Sleep monitoring	MS51	Metals melting	-	Student investigations	+S014	Diffusion in liquids
MS51	Time and motion study	MS52	Exothermic brazing	ED11	Atmospheric attenuation of energy	S015 (TV115)	Ice melting
MI71	Metabolic activity	MS53	Sphere forming	ED12	Libration clouds	S016 (TV116)	Ice formation
MI72	Body mass measurement	MS58	Radioactive tracer diffusion	ED21	Objects within Mercury's orbit	S017 (TV117)	Effervescence
S015*	Effects of zero gravity on single human cells	MS59	Microsegregation in germanium	ED22	Quasars	S018 (TV118)	Immiscible liquids
S021*	Circadian rhythm, pocket mice	MS60	Growth of spherical crystals	ED23	X-ray stellar classes	S019 (TV119)	Liquid floating zone
S072*	Circadian rhythm, vinegar gnat	MS61	Whisker-reinforced composites	ED24	X-rays from Jupiter	S020 (TV120)	Deposition of silver crystals
	<u>Solar physics</u>	MS62	Indian antimonide crystals	ED25	Ultraviolet emissions from pulsars	S021 (TV121)	Liquid films
+S220	X-ray and ultraviolet solar photography	MS63	Mixed III-V crystal growth	ED26	Bacteria and spores	S022 (TV122)	Lens formation
S052	White light coronagraph	MS64	Metal and halide eutectics	ED31	In vitro immunology	S023 (TV123)	Acoustic positioning
S054	X-ray spectrograph	MS65	Silver grids melted in space	ED32	Microorganisms in varying gravity	S024 (TV124)	Gyroscopes
S055A	Ultraviolet scanning polarimeter	MS66	Copper-aluminum eutectic	ED33	Motor sensory performance	S025 (TV125)	Cloud formation
S056	X-ray telescope	M479	Zero gravity flammability	ED41	Chick embryology	S026 (TV126)	Orbital mechanics
S067A	Extreme ultraviolet spectroheliograph			ED51	Web formation	S027 (TV127)	Rochelle salt growth
S067B	Spectrograph and extreme ultraviolet monitor			ED52	Plant growth and plant phototropism	S028 (TV128)	Neutron environment
-	Hydrogen-alpha			ED61-62	Cytoplasmic streaming	S029 (TV129)	Charged particle mobility
	<u>Earth observations *</u>			ED71	Capillary study		
S190A	Multispectral photographic facility			ED74	Mass measurement	+ Johnson Space Center development responsibility	
S190B	Earth terrain camera			ED75	Brownian motion	+ Johnson Space Center integration responsibility	
S191	Infrared spectrometer			ED76	Neutron analysis		
S192	Multispectral scanner			ED77	Universal gravity		
S193	Microwave radiometer, scatterometer, and altimeter			ED78	Liquid motion		
S194	L-band microwave radiometer						

In spite of the difficulties experienced with the Saturn Workshop during the first few days, the total experiment results far exceeded all expectations, and the overall performance of the experiments was exceptional. There were problems that were the direct result of the launch anomaly; others were instrument or operations problems. Problems are classed as anomalies if they caused consideration of mission changes and are reported in some detail with the affected experiment.

Data from the experiments were returned in several forms, including telemetry, photography, television, crew voice, logs, crew debriefing, and samples. Approximately one-half of the experiments used photography and ranged in the electromagnetic spectrum from 0.1 to 160,000 angstroms. More detailed information on the experiments and their performance can be found in references 6 and 7. The experiment results will be forthcoming in separate reports as the investigators complete their analyses.

### 12.1 SOLAR PHYSICS

The solar physics experiments, except for the X-ray and ultraviolet solar photography experiment (S020), were incorporated into the solar observatory, which provided common pointing, roll, power, and thermal control. The instruments viewed the entire solar disk and corona and provided high resolution data in the spectral range of 2 to 7000 angstroms. The instrument arrangement and spectrum ranges are shown in figure 12-1. In addition to the solar observations, the instruments collected data on the Comet Kohoutek, Mercury's atmosphere, Earth-Moon Lagrangian points, lunar libration points, and the Earth's atmosphere.

- |   |  |
|---|--|
| A. X-ray telescope (S056)                     | G. Hydrogen alpha 2 telescope                          |
| B. X-ray event analyzer (S056)                | H. Spectrograph and extreme UV monitor (S0P2B)         |
| C. Fine sun sensor                            | I. UV scanning polychromator spectroheliometer (S055A) |
| D. X-ray spectroheliographic telescope (S054) | J. Hydrogen alpha 1 telescope                          |
| E. Extreme UV spectrograph (S082A)            | K. White light coronagraph                             |
| F. Spar                                       |  |

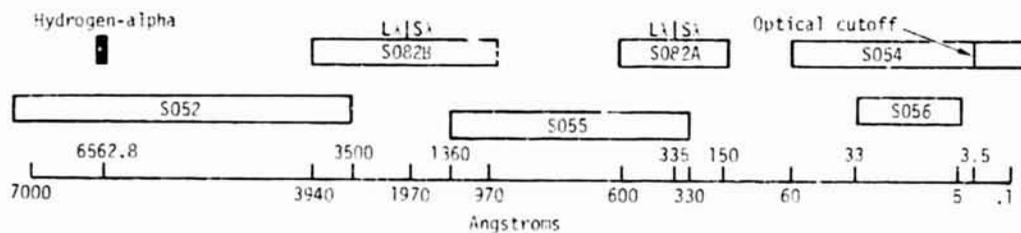
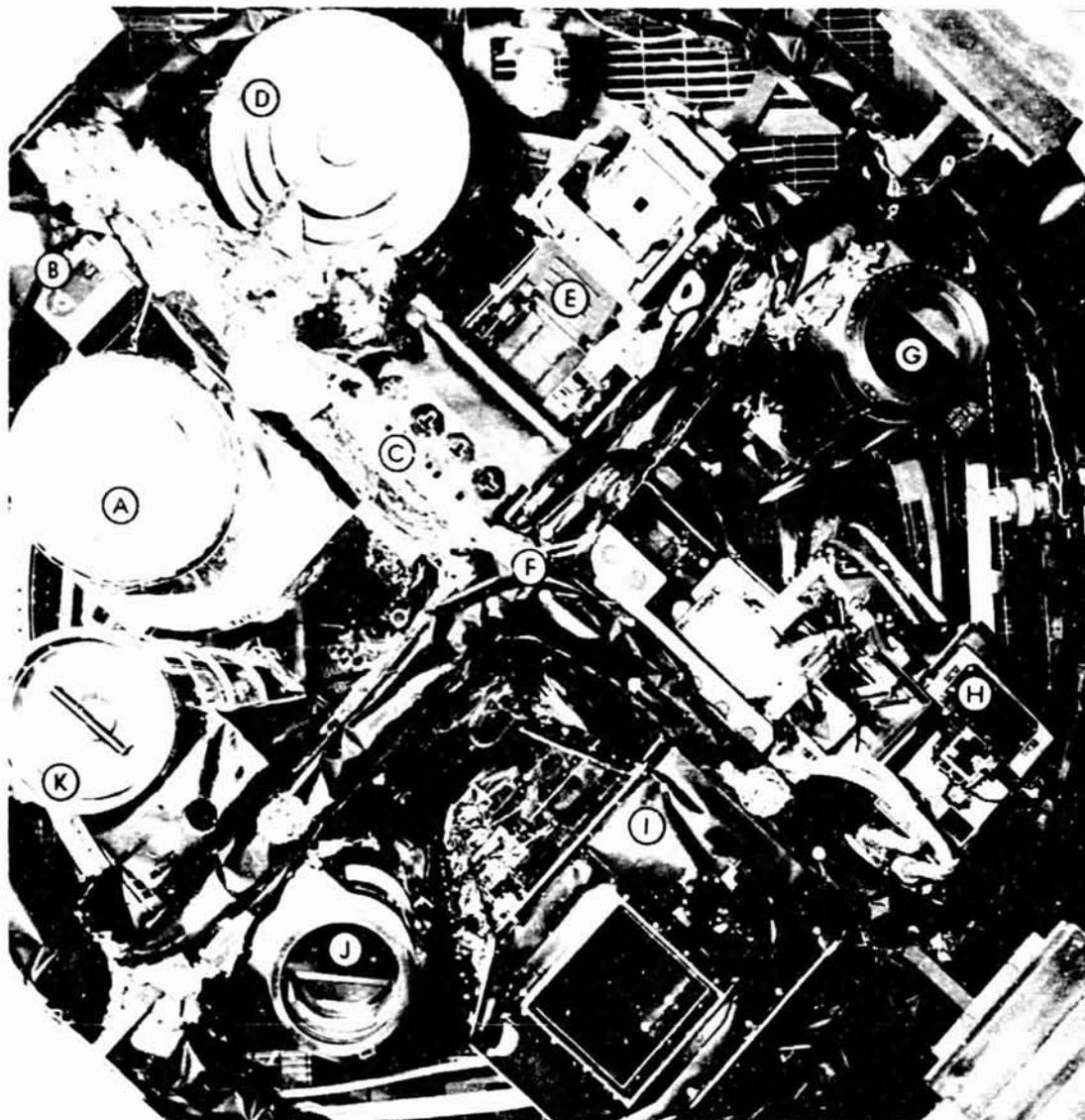


Figure 12-1.- Solar observatory instrument arrangement and spectrum coverage.

The instruments were operated from the control console (fig. 12-2) by the crew during attended viewing operations. Switch configurations were selected by the crew before unattended and unmanned periods for those instruments that were capable of unattended operation.

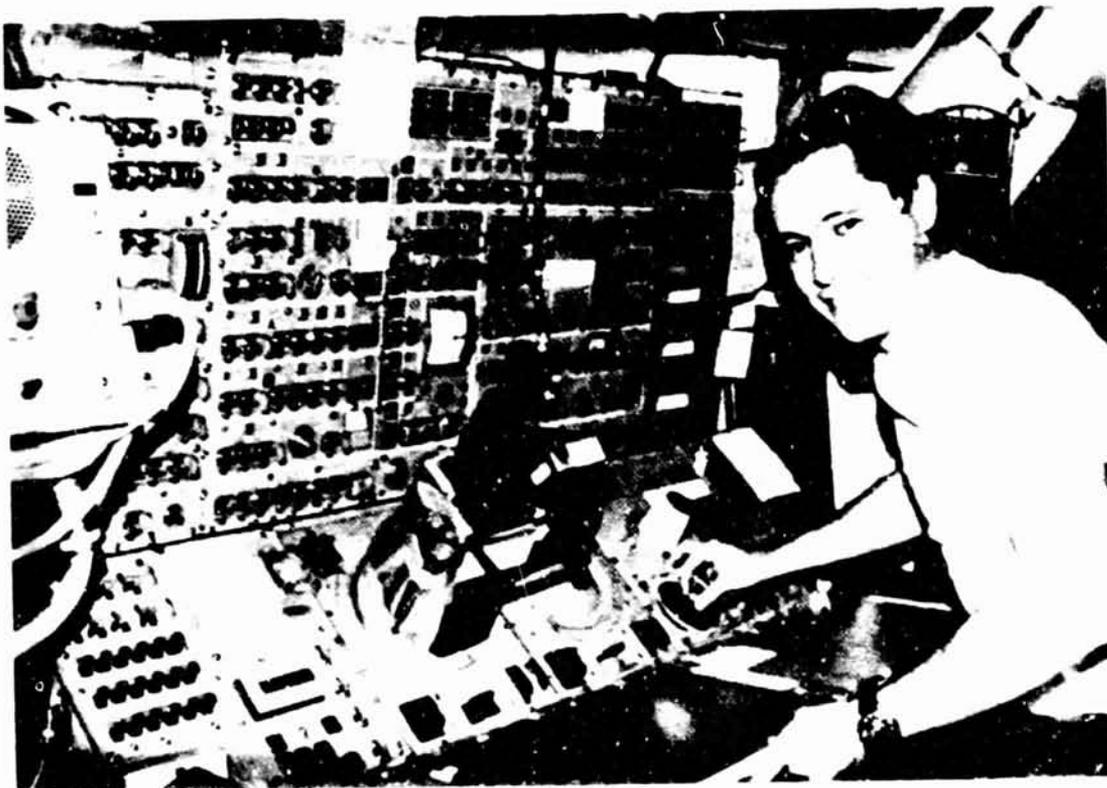


Figure 12-2.- Crewman at solar observatory control and display console.

Table 12-II.- Joint Observing Programs

Program number	Title
1	Chromospheric network and its coronal extension
2	Active regions
3	Flares
4	Prominences and filaments
5	Limb profile studies
6	Synoptic observations of the Sun
7	Atmospheric extinction
8	Coronal transients and disk transients
9	Solar wind
10	Lunar libration clouds
11	Chromospheric oscillations and heating
12	Program calibration
13	Observations of night sky objects
14	Solar eclipse
15	Coronal holes
16	Disk transients
17	Coronal bright spots
18	Comet Kohoutek
19	Alfven waves in the corona
20	Rapidly changing coronal structures
21	Time variations in coronal structures
22	Radio oscillation
23	Mercury transit
24	Latitude variation of chromospheric structure
25	S055A maxi raster and super raster
26	Coronal structures
27	Velocities

Initially, each of the instruments had a unique set of scientific objectives and was designed to operate independently. To use viewing time more efficiently, a joint observing program, presented in table 12-II, was developed for each major scientific investigation. This enabled the instruments to collectively observe selected phenomena. The individual instrument configuration and operations were defined as building blocks. The joint observing programs consisted of various combinations and multiples of those building blocks. This approach incorporated flexibility in selecting the data acquisition method for a particular investigation. Typical building blocks are shown in figure 12-3.

The effectiveness of the solar observatory is demonstrated by the quality of the telemetered data and film data. These data are superior to any previously obtained

and are expected to result in significant scientific discoveries that may revise theories of solar physics and Earth science.

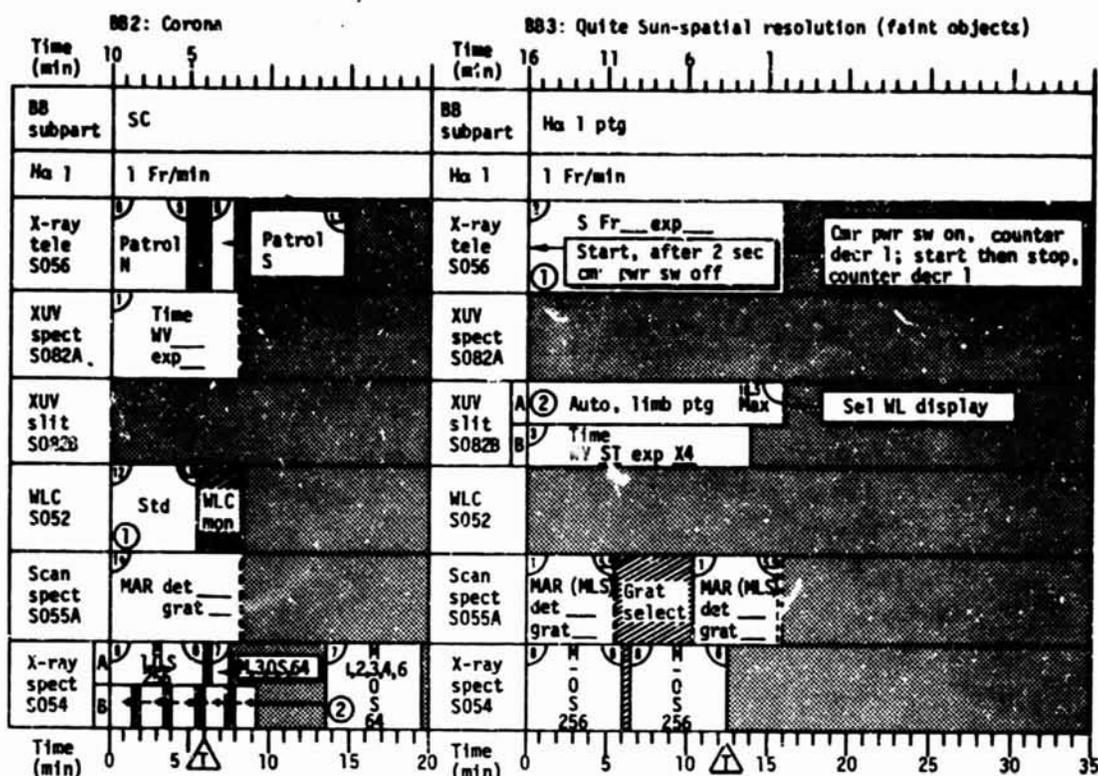


Figure 12-3.- Typical building blocks.

#### 12.1.1 White Light Coronagraph (S052)

The white light coronagraph (S052) blocks out the image of the Sun's disk and photographs the solar corona in the visible region (3500 to 7000 angstroms) of the electromagnetic spectrum. The field of view is from 1.5 to 6.0 solar diameters.

The instrument, shown in figure 12-4, consists of optics, a film camera, a television camera, a pointing reference system, associated electronics, and a thermal control system. External and internal occulting disks and a Lyot spot block the light from the solar disk. Internal apertures and light baffles reduce the scattered light and internal reflections. The lenses then produce an image of the corona on the film plane or in the television camera, and folding mirrors shorten the overall instrument length. Calibration wedges provide a coronal brightness intensity calibration pattern at the center of each film exposure. A four-position polaroid wheel provides polarization data of the solar corona, and the 35-millimeter sequential camera records the coronal image, calibration pattern, time of day, roll position, exposure time, experiment mode, internal alignment error, pointing error sensor, and polarization wheel position on each frame. The television camera provides the crew with real-time monitoring. The pointing reference system provides error signals for pointing the instrument optics axis to the center of the solar disk and error signals for alignment of the internal occulting disk with the optics axis. Electronics provide command

and control from the control console and from the ground, and the telemetry monitoring signals. The instrument temperatures are controlled by an active and passive thermal control system.

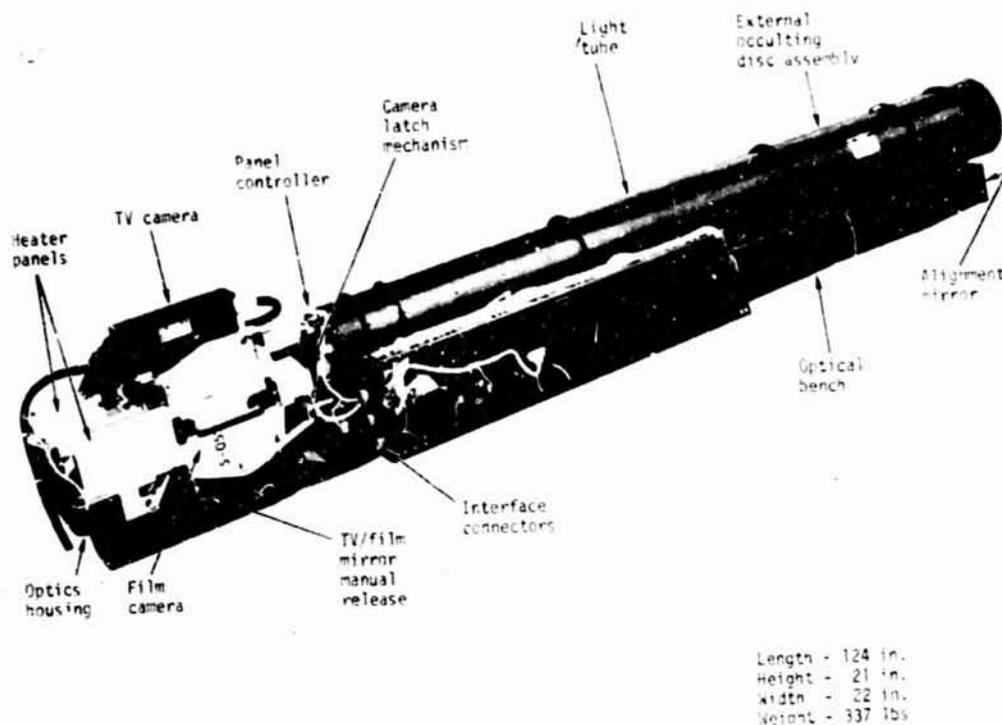


Figure 12-4.- Experiment S052 white light coronagraph.

Performance of the instrument was excellent throughout the mission. The crew, making real-time adjustments to the observing programs and taking corrective actions in orbit, greatly improved the quality of the data and minimized the effect of anomalies. More observation time of the Sun's corona was obtained during the first few days of the mission than had been accumulated in all previous history. The scattered-light level in the instrument was 1 to  $2 \times 10^{-10}$  times the brightness of the Sun, the lowest of any previous coronagraph. The design specification requirement of 56 days for orbital operating life was considerably exceeded, as the instrument was still operational at the conclusion of the mission. The television display proved useful to the crew and to the scientists on the ground. Pre-mission requirements of 3 to 5 minutes of television observation or downlink once per day was changed to twice per day during the mission. Except for brief periods of perturbation due to crew motions, a spatial resolution of 8 arc-sec was achieved, exceeding the instrument design specification of 15 arc-sec, and equaling the limiting resolution of the film.

The duration of the mission permitted observation of the corona during several rotations of the Sun (approximately 4 weeks per rotation). The dynamics of some coronal features were shown to have time scales on the order of one-half the period of rotation of the Sun. Some coronal features were observed to have time scales on the order of days. With observing periods of approximately 1 hour out of every 1.5 hours (period of Skylab orbit), other coronal features were observed with time scales on the order of hours. The fast-scan mode permitted observation of coronal dynamics with time scales on the order of minutes.

Some changes were observed between frames taken 40 seconds apart. Opportunity for extensive observation of solar corona dynamics on these time scales had never before been afforded.

During the mission, five film cameras containing 35-millimeter Kodak Special 026-02 thin base film were used to obtain a total of 35,918 frames. Evaluation of developed film indicated that exceptionally high quality photographic data were obtained, with considerable coronal detail visible on the film. The photographs brought out a wealth of detail on the structure of the corona. The coronal structure was enhanced by the instrument's vignetting feature, which allowed more light to be viewed from the outer corona than from the inner corona. Together with the three lengths of exposure (3, 9, and 27 seconds), this vignetting served to extend the effective photographic dynamic range of the instrument, permitting very faint outer-coronal detail observation on long exposures, and inner-coronal detail without blooming on short exposures. As an example, figure 12-5, a photograph in unpolarized light, is one of a sequence of 144 frames taken of an eruptive prominence, moving outward from the solar limb into the corona. The loop structures are material, moving outward, with a velocity of approximately 450 km/sec. This rare event was observed for approximately 0.5 hour.



Figure 12-5.- White light corona-graph filmed corona detail.

velocity of approximately 450 km/sec. This rare event was observed for approximately 0.5 hour.

On Day 28 an unusual rate of temperature rise was observed inside the film camera. The rate of rise was comparable to that derived by computer simulation for a stalled film transport motor. At the next scheduled operation of the instrument, the crew reported that the operate light did not illuminate and the frames-remaining counter did not decrement. The anomalous temperature condition recurred. The crew had performed the applicable malfunction procedure, which indicated a possible film camera or primary programmer failure. Since further film camera operation was not possible until the camera was replaced, coronal observations were performed using television downlink. A second film camera was installed and checked out, and it operated properly. There was minimal data loss as a result of this anomaly. Postflight examination showed that the film was torn apart. After the film was torn, it had piled up around the supply-side drive sprocket until it jammed and stalled the transport motor.

#### 12.1.2 X-Ray Spectrograph (S054)

The X-ray spectrograph (S054) studies solar emissions in the soft X-ray spectrum (from 3 to 60 angstroms). The instrument photographs solar flares within this spectrum during active periods and obtains broadband X-ray photographs in selected regions of the X-ray spectrum during non-flare periods. A field of view of 48 arc-min covers the entire solar disk.

The instrument, shown in figure 12-6, consists of a telescope, an image dissector, a photomultiplier, a film camera, a thermal control system, and

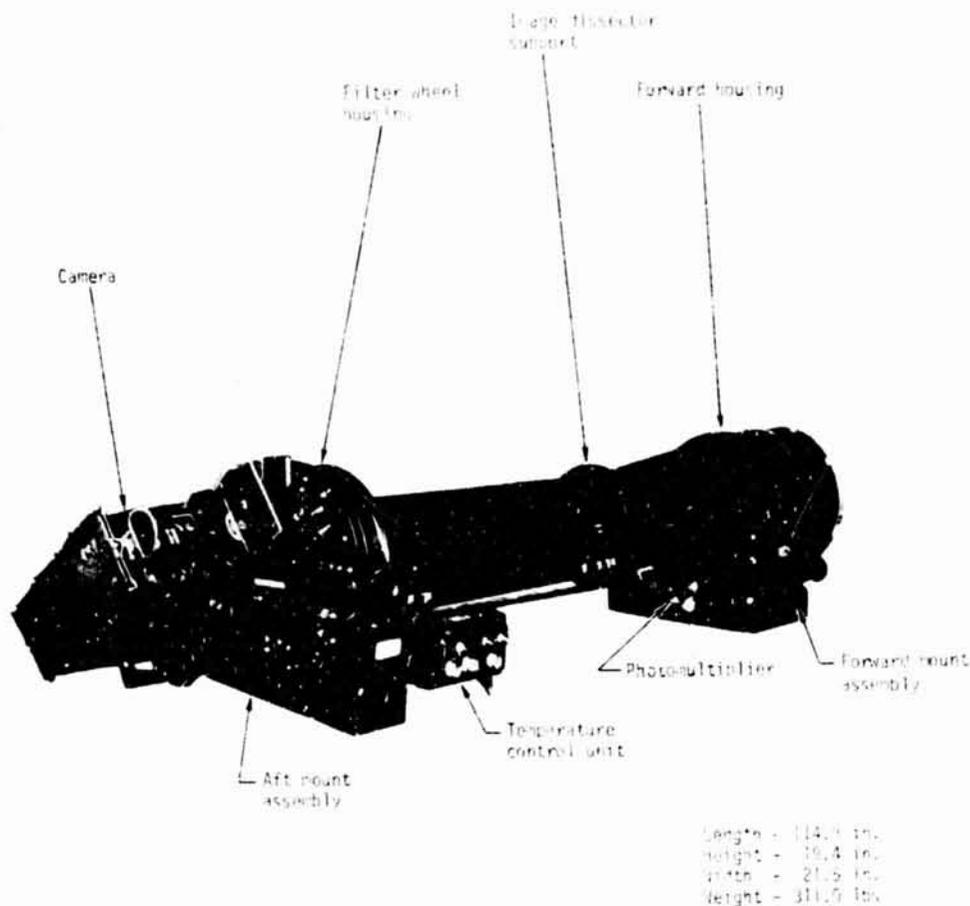


Figure 12-6.- Experiment S054 X-ray spectrographic telescope.

necessary supporting electronics. The mirror assembly and lens provide X-ray and visible images of the Sun. An X-ray transmission grating produces a dispersed image of the Sun when positioned in the optical path, yielding moderate resolution X-ray spectroheliograms. The image dissector senses flare activity and provides a display for the crew on the X-ray image monitor for flare viewing and a display of the total counts per second on the image intensity counter. Filters in the filter wheel produce broadband X-ray photographs of the Sun. A photomultiplier monitors the intensity of the X-ray flux, provides the crew with information on X-ray activity, activates the flare alarm and automatic camera operation, and supplies data for pulse height analysis in the 10 to 100 keV range. The film camera records visible and X-ray images, records status of instrument operation, and provides time correlation for each exposure. The electronics provide control from the control console and from the ground and supply the telemetry monitoring signals. The instrument temperatures are controlled by a fully redundant primary and secondary thermal control system.

The instrument successfully accomplished mission objectives. More than 31,000 photographs were obtained using four film magazines and one magazine

reload. Additional X-ray data were obtained by the photomultiplier and image dissector systems, which provided intensity and pulse height information on solar activity. The instrument operated throughout the mission and exceeded its orbital life requirement of 42 days.

There were two discrepancies. On Day 36 an instrument logic reset occurred that affected two telemetry measurements: picture count and X-ray shutter duration. The resets continued randomly throughout the mission; however, only the telemetry was affected. The cause of the resets could not be determined. On Day 217, the crew reported that the lowest 40 percent of the X-ray image monitor intermittently disappeared. Analysis indicated the problem was caused by an intermittent connection between the main electronics assembly and the control console. Operations were not hampered and no repair action was necessary.

Developed film was of excellent optical quality, indicating that alignment of the telescope optical elements was maintained. Spatial resolution was better than 2 arc-sec, which compares favorably to the design requirement of 3 arc-sec. Spectral resolution was 50 at 7 angstroms with the design requirement being 30 at 7 angstroms. No noticeable jitter or drift was evident on the photographs except as anticipated, when the solar observatory experiment pointing control was disabled. Figure 12-7 is a photograph of the solar disk. Dispersed images from 3 to 60 angstroms were recorded during the second and third manned periods.

No dispersed images were obtained during the first manned periods since the X-ray transmission grating was not used.



Figure 12-7.- Experiment S054 X-ray photograph of the solar disk.

The first solar flare to be detected occurred on Day 33. Approximately 390 exposures were obtained showing flare growth in the X-ray region. Photoelectric flare data were telemetered to the ground and plotted as shown in figure 12-8. The effect of the South Atlantic Anomaly radiation is also illustrated. Figure 12-8 also shows a response curve of the intensity monitor output during the flare.

When the crew moved the filter wheel, the shutter was bent, and subsequently the shutter moved into the optical path. The shutter opening was cleared by bending the shutter out of the way, and the filter wheel was moved to position 3 (no filter). During installation of the camera magazine, the bent shutter partially moved into the optical path again. This produced several shadows on the X-ray image, resulting in some data loss. During the end-of-mission closeout activities, the filter was commanded from position 3 to position 1. It drove normally through positions 4, 5, and 6 at that time. Moving the wheel manually cleared the filter mechanism of mechanical obstructions.

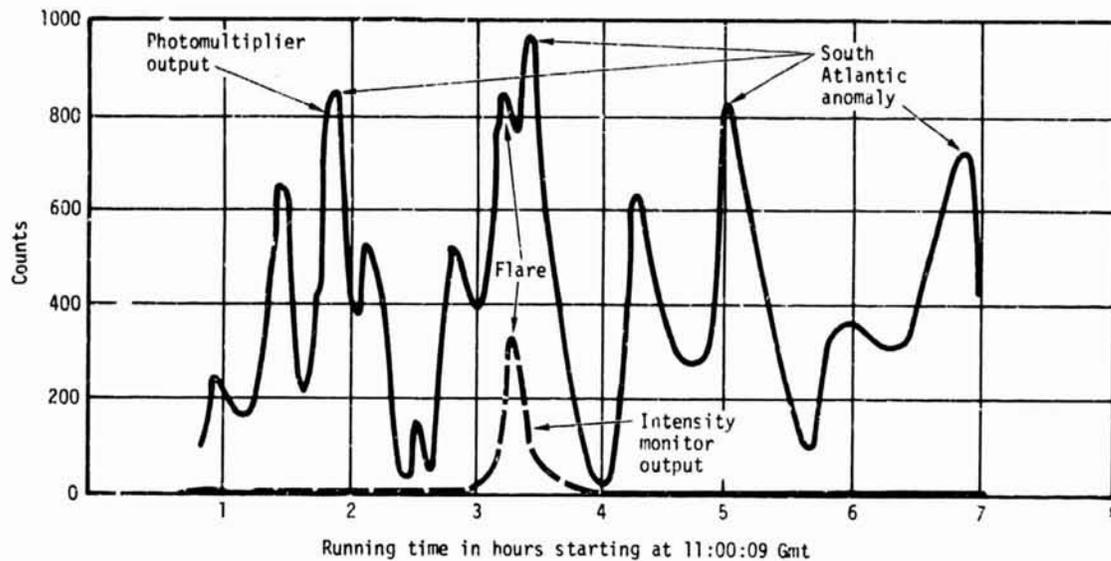


Figure 12-8.- X-ray flare response on Day 23.

#### 12.1.3 Ultraviolet Scanning Polychromator Spectroheliometer (S055A)

The ultraviolet scanning polychromator spectroheliometer (S055A) measures the intensity of solar radiation from selected regions of the Sun in the far ultraviolet wavelength region of 300 to 1350 angstroms with a 5 by 5 arc-sec field of view.

The instrument, shown in figure 12-9, consists of a telescope, a spectrometer, a thermal control system, and related electronics. Unlike the other observatory instruments, this instrument carries no film. The telescope employs an off-axis parabolic primary mirror to collect solar radiant energy and image a portion of the collected energy at the entrance slit of a concave grating spectrometer. A spherical concave grating disperses the incoming radiation into a spectrum, and seven ultraviolet detectors and one visible range detector detect the radiation. The electronics provide control of the instrument from the control console and from the ground, process the detected radiation, and provide telemetry monitoring signals. The instrument has both an active heating system and a passive insulation system to maintain temperature control.

The instrument successfully accomplished the mission objectives and exceeded its orbital life requirement of 56 days, performing within design specifications throughout the mission. Data were obtained in the ultraviolet wavelength region for construction of spectroheliograms to examine temperature changes between regions at super granulation, to measure the apparent size of the Sun at various wavelengths, and to determine the temperature and density structure of the low corona.

Crew participation in solar observing programs greatly enhanced collection of scientific data. Periods designated for selection of targets of opportunity, left solely to the discretion of the crew, provided an excellent means by which data collection decisions based on real-time solar conditions could be made.

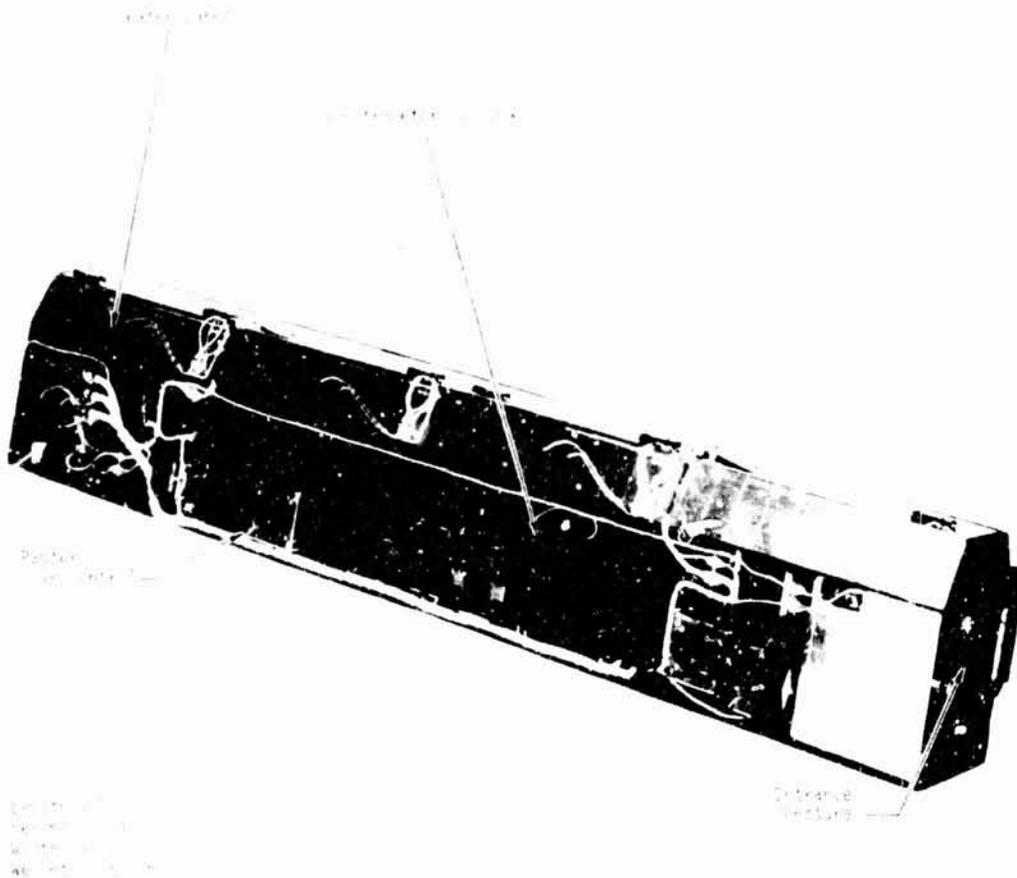


Figure 12-9.- Experiment S055A extreme ultraviolet scanning polychromator spectroheliometer.

Instrument pointing was made available to the crew through the use of the primary mirror position readout. This feature was of particular value for detecting points of maximum intensity in mirror modes, and then returning to those locations and initiating a grating scan for further study. This technique was used during observations of the limb to detect prominences or loops, and during observations of the disk to study bright spots. Of particular significance was the flare precursor provided by the instrument indications. When solar bright points began changing location and magnitude, and high intensity counts were indicated at the oxygen VI line (1032 angstroms), flare activity could be expected.

The total operating time for the instrument was 2292 hours. Of this total time, approximately 1719 hours were used performing mirror raster scans and 573 hours were spent performing grating scans, resulting in approximately 18,750 raster scans and 9880 grating scans.

During the mission several ultraviolet detector high voltage tripouts occurred. The ultraviolet detectors were designed with a built-in, current-sensing overload protection device with automatic cutoff and manual reset. This turnoff (tripout) could have been caused by high voltage corona breakdown, internal pressure buildup, or external sources. Total data loss from all tripouts was within the anticipated level.

The quality of the data obtained by the instrument was excellent and indicated extremely good optical and electrical performance. Figure 12-10 is an example of a spectroheliogram constructed from the data.

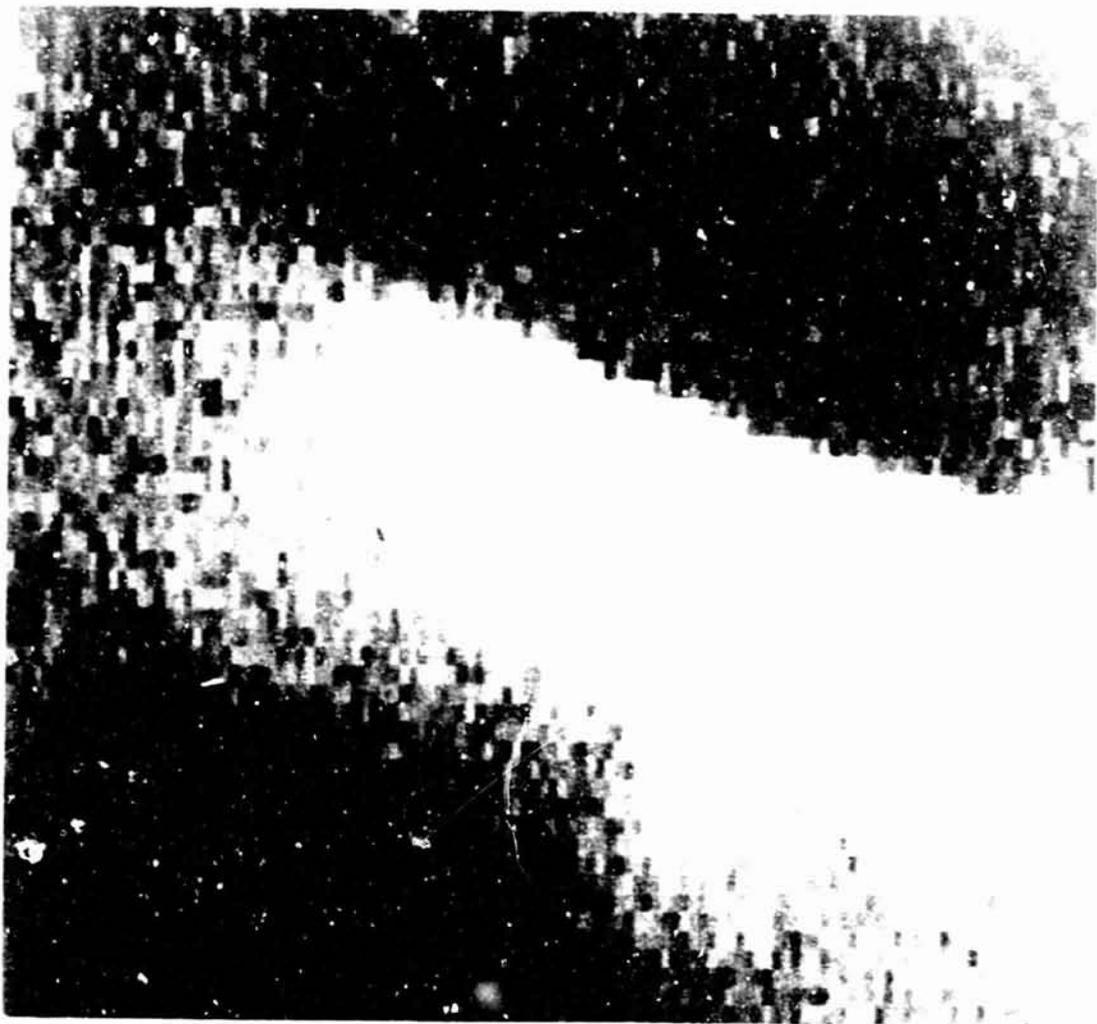


Figure 12-10.- Experiment S055A spectroheliogram of a solar prominence.

#### 12.1.4 X-Ray Telescope (S056)

The X-ray telescope (S056) obtains X-ray filtergrams (solar images of narrow wavelength intervals) in five bandwidths from 5 to 33 angstroms and one in the visible light range ( $6328 \pm 40$  angstroms). The instrument is equipped with an X-ray event analyzer to obtain spectral data (intensity versus wavelength) in 10 wavelength bands from 2.5 to 20 angstroms.

The instrument, shown in figure 12-11, consists of a telescope with glancing-incidence mirrors, a film camera, thermal control system, an X-ray event analyzer, and necessary electronics. A parabolic-hyperbolic cylindrical glancing-incidence mirror focuses the solar image on the focal plane of the camera. Filters in the

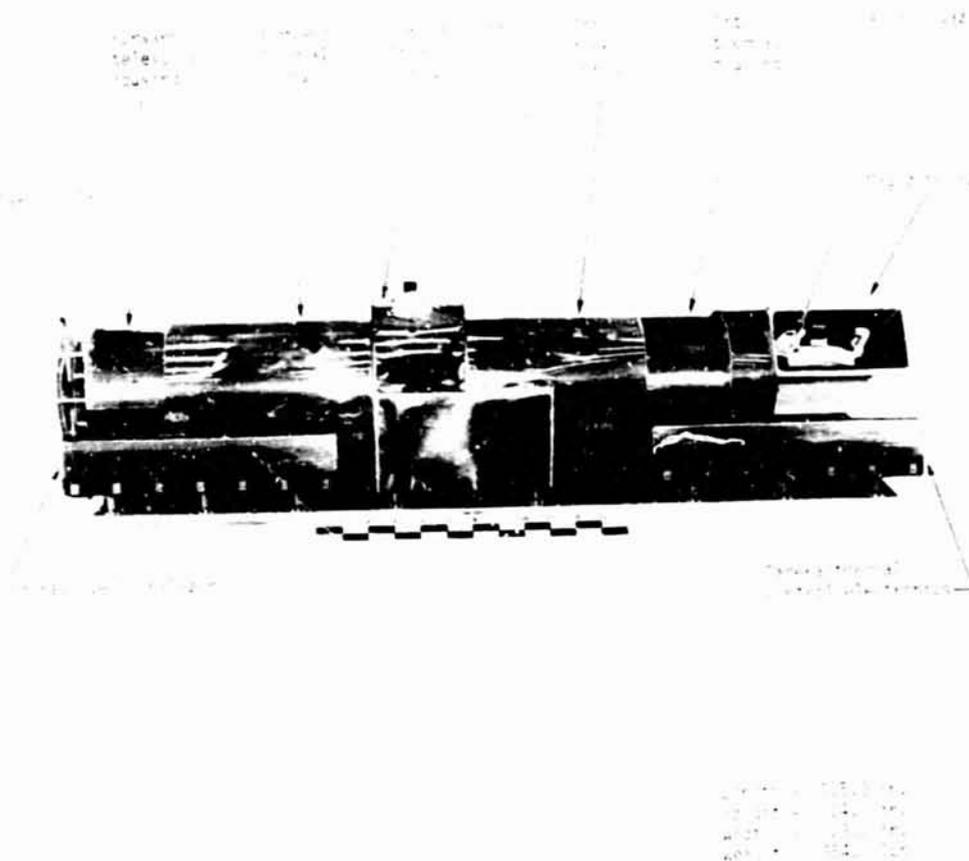


Figure 12-11.- Experiment S056 X-ray telescope.

filter wheel produce whole-disk images in the required X-ray spectra range, and the film camera records the image on film along with data describing conditions existing at the time of exposure. An X-ray event analyzer consisting of two proportional counters with thin, metallic windows (one of beryllium and one of aluminum) detects the total X-ray intensity in two wavelength regions. A pulse height analyzer sorts and counts the proportional counter output pulses with respect to amplitude into six channels corresponding to six energy levels for beryllium and four channels corresponding to four energy levels for aluminum. The electronics provide command and control from the control console and from the ground, and provide the teleretry signals. The instrument thermal control system combines passive techniques with an active system to maintain temperatures.

The instrument successfully accomplished mission objectives. More than 27,000 X-ray photographs were recorded by the film camera and more than 1100 hours of X-ray spectral data were displayed and telemetered to the ground. Five film loads were used throughout the mission. Four of these magazines were loaded with 35-millimeter, SO-212 black and white film, and one with SO-242 color film. All film camera exposure sequences were selected as well as the normal, long, and short exposure settings necessary to satisfy solar viewing requirements. Longer duration exposures than those programed in the camera electronics were obtained by leaving the shutter open when the camera was powered down.

Evaluation of the film data from the second manned period revealed that a light leak developed in filter 3 that allowed visible light to penetrate and partially expose the film. All six filters were subjected to exposure times in excess of the premission operating requirements, but only filter 3 was damaged. This impacted the scientific data as filter 3 was the only filter that covered the 27- to 33-angstrom range. Indications were that the damage to filter 3 was due to thermal stress which caused perforations of the filter material or to a manufacturing defect that allowed the filter to lift out of the filter wheel. The exact cause of the problem remains unknown.

On Day 197, the crew reported that the beryllium display counter on the control console failed to indicate any X-ray activity. Telemetered data verified that the beryllium detector was functioning. Thereafter the beryllium data could only be monitored by the ground. The cause of this problem was not determined.

The overall X-ray image quality of the film was good and indicated stable optical performance of the telescope. Figure 12-12 is a representative photograph taken by the camera. The X-ray event analyzer obtained 1174 hours of spectral data and was the first instrument to detect the major solar flare that occurred on Day 33. During the flare, the X-ray flux through the beryllium filter (7.25 angstroms), rose to 500,000 counts per second in approximately 5 minutes.



Figure 12-12.- Experiment S056  
X-ray solar activity.

The instrument experienced one anomaly. Operational modes terminated prematurely during the exposure sequences. The terminations were caused by the loss of the film advance pulse. Excessive mechanical drag buildup in the magazine caused by the antistatic backing from the film being deposited on the clutch surfaces occasionally prevented the film drive motor from advancing the film a complete frame. This caused the film-advance decoding system to indicate a short frame. Sufficient short frames in sequence would cause the film-advance decoding system to indicate no film advance, shutting the camera off until it was restarted. From all data examined and tests performed, the conclusion was that the mechanical drag buildup was sufficient to stall the film drive motor. The data loss was negligible and was more than compensated for by the increased number of photographs obtained over what was planned.

#### 12.1.5 Extreme Ultraviolet Spectroheliograph (S082A)

The extreme ultraviolet spectroheliograph (S082A) photographically records images of the solar chromosphere and corona to 1.5 solar radii (when Sun-centered) in the wavelengths between 150 and 625 angstroms on 35- by 258-millimeter film-strips.

The instrument, shown in figure 12-13, consists of a grating, a filmstrip camera, a thermal control system, and related electronics. A two-position single

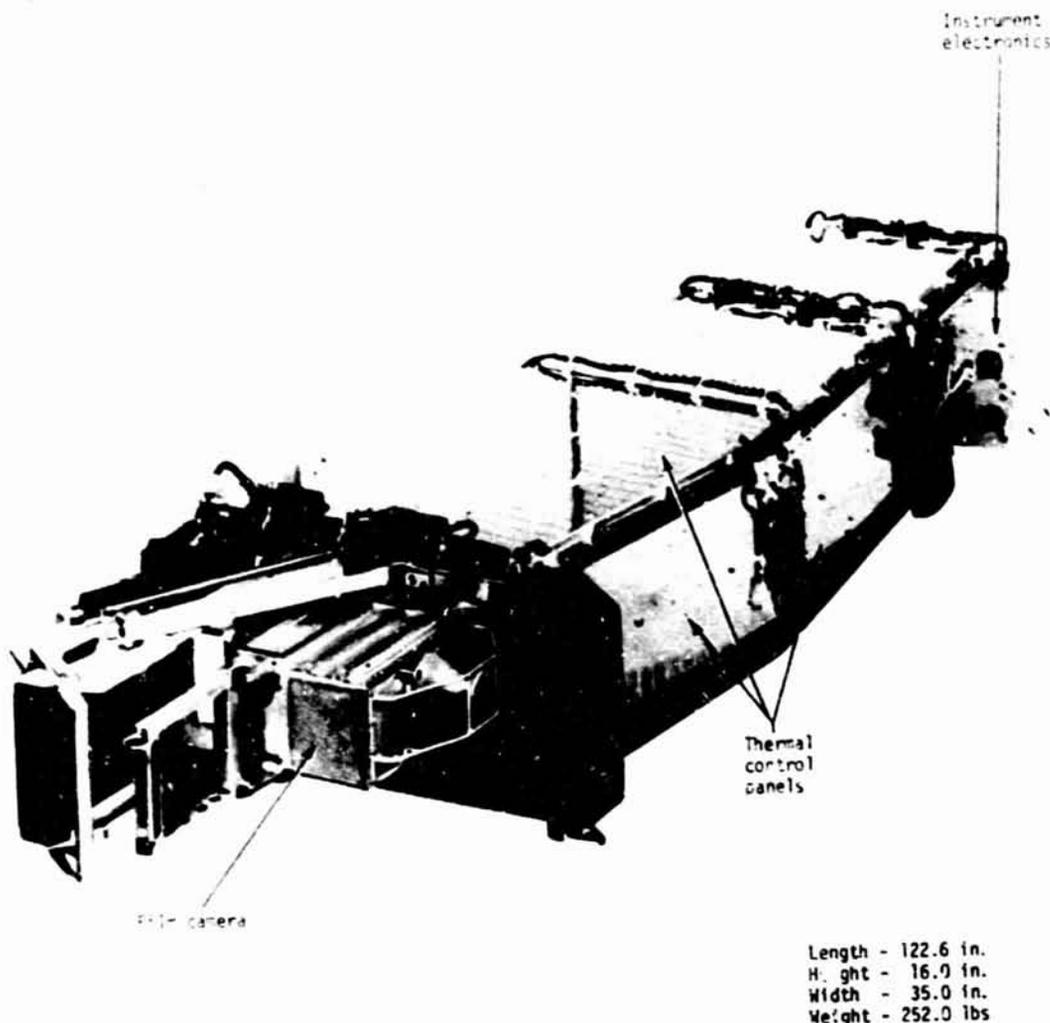


Figure 12-13.- Experiment S082A extreme ultraviolet spectroheliograph.

spherical concave grating diffracts the full solar image into its spectral components and focuses the diffracted image onto the filmstrip camera. The heat rejection mirrors reject zero order white light and heat. A thin aluminum filter limits wavelength bandpass and prevents film fogging from stray light. A diode matrix data flasher records the time at the beginning and end of the exposure. The filmstrip camera records rows of overlapping images of the full solar disk, each representing a different wavelength. The electronics provide control from the control console and from the ground, and provide telemetry monitoring signals. The instrument thermal control system uses heater panels for temperature control.

Instrument performance was excellent during the mission. Although the instrument was designed for a life requirement of 56 days, it remained fully operable throughout the mission. The 6 film cameras obtained 1024 high resolution photographs using extreme-ultraviolet-sensitive type 104 film except for the 5 frames of type 101 film in load 6 for Comet Kohoutek viewing. One camera was installed on the instrument at launch, two were stored in the docking adapter

film vaults, one was resupplied for the second manned period, and two were resupplied for the third manned period.

Evaluation of the photographs revealed fine detail and excellent optical quality. All scientific objectives were accomplished, and the spectroheliograms obtained from the film cameras indicated proper functioning of the instrument optics. Figure 12-14 is a photograph taken by the film camera and is representative of the photography achieved throughout the mission.

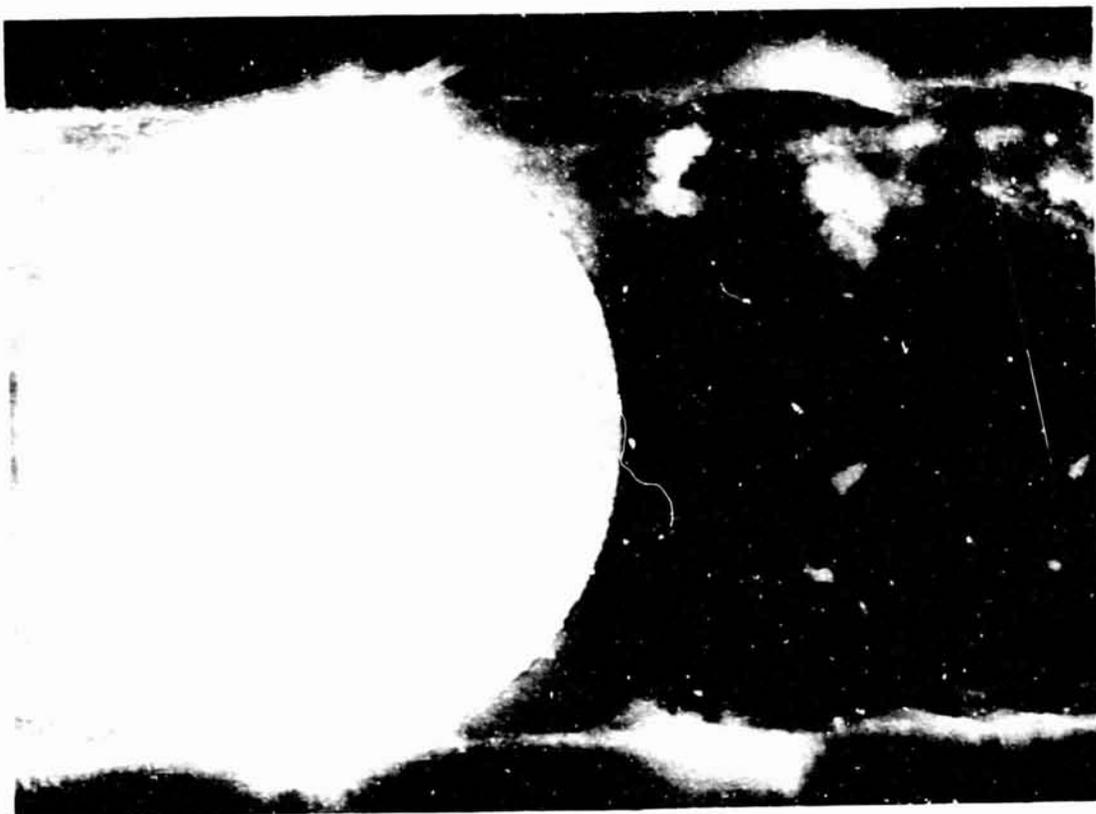


Figure 12-14.- Experiment S082A film camera photograph.

The instrument experienced two anomalies during the mission. On Day 17, the crew indicated that the frames-remaining counter failed to decrement. Telemetry verified the failure by absence of the film transport signal. The cause of the failure was determined to be a jammed camera. The camera was exchanged on Day 25. The replacement camera was cycled and the frames-remaining counter and all ground telemetry indicated proper operation. The failed camera was evaluated and found to have jammed on the 19th exposure. Although the failure mode was identified, the cause could not be positively identified. The problem did not recur with any of the other four cameras used during the remainder of the mission.

On Day 145, following processing and evaluation of film from the second manned period, parallel horizontal pairs of streaks were observed on the film. The streaks were also present on the first manned period film, but to a lesser extent. The streaks corresponded to the stiffening ribs in the film holder. Not all of the wavelength images were affected and only a small part of the images that were affected were degraded. The images contained acceptable scientific data; however, the ribbed film holders were replaced with nonribbed aluminum film holders on the remaining cameras. Evaluation of film data confirmed that the use of nonribbed aluminum film holders eliminated the streaks.

### 12.1.6 Spectrograph and Extreme Ultraviolet Monitor (S082B)

Experiment S082B's spectrograph photographs line spectra of small selected areas on and off the solar disk and across the limb in two wavelength bands: 970 to 1970 angstroms or 1940 to 3940 angstroms. The extreme ultraviolet monitor observes a video image of the full solar disk in the wavelength band from 170 to 550 angstroms and identifies solar features of interest.

The instrument, shown in figure 12-15, consists of two telescopes, a pointing reference system, a spectrograph, a filmstrip camera, a thermal control system, and associated electronics. An off-axis parabolic mirror focuses the solar

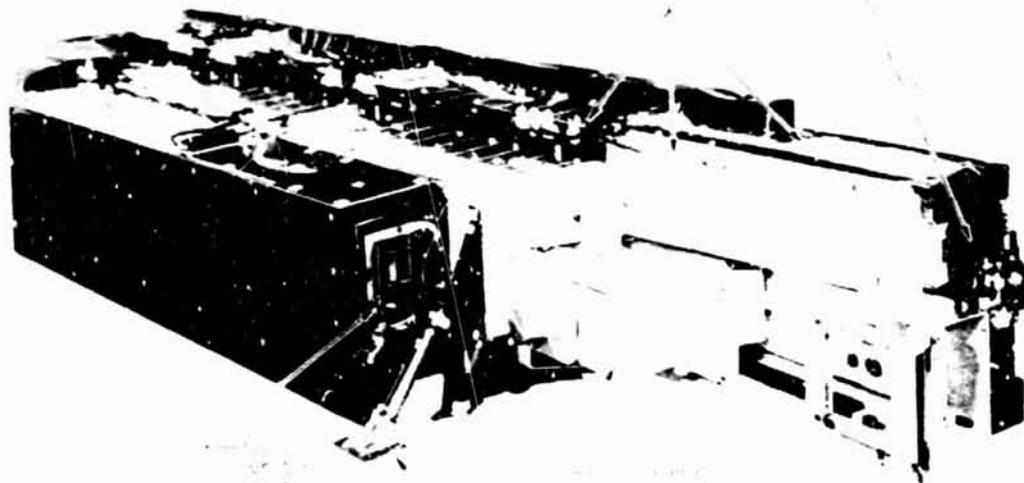


Figure 12-15.- Experiment S082B spectrograph and extreme ultraviolet monitor.

image on a spectrograph entrance slit that allows selected portions of the solar disk or limb to be viewed. The two predisperser gratings diffract the light from the slit and a waveband aperture passes the predispersed portion of the spectrum to the main concave grating. The main grating then diffracts the predispersed spectrum and focuses it onto the filmstrip camera. The filmstrip camera records lines representing different wavelengths in the spectrum. A pointing reference system generates a standard television picture of the Sun's limb, provides a digital indication of the angular distance between the limb and the slit, and controls the distance between the limb and slit. A separate television monitor system is used to view the solar disk in the 170- to 550-angstrom

range. The electronics provide control from the control console and from the ground, and provide telemetry monitoring. The thermal control system consists of an active heating and passive insulation system for controlling and stabilizing temperatures.

The instrument successfully accomplished mission objectives. Four film cameras were used and 6411 photographs were obtained. The instrument significantly exceeded its designed 56-day orbital life period and remained operable throughout the mission.

When the crew recorded the extreme ultraviolet monitor video for downlink transmission, a series of integration times was used. These were standardized at 0.5, 1, 2, and 4 seconds. This had the effect of greatly extending the contrast range of the camera. In the short integrations, very few Sun features had reached saturation. In the long integrations, most Sun features had reached saturation, but some dim features contained detail not yet detected in the shorter integrations. Ground analyses used these schemes to extend the extreme ultraviolet monitor usefulness. Crew coordination conferences were held using the data as a point of reference for solar activity. The combination of these techniques steadily increased the usefulness of the monitor during the mission. Although the monitor had been of minimum value to the crew during the first manned period, it was an important factor in planning the daily solar observatory data-taking schedule. During the second and third manned periods, the monitor was used extensively by the crew.

The 2 film cameras used during the second manned period caused a loss of 21 exposures. The first camera stopped transporting 16 frames early when a lockout device actuated prematurely. A noisy film transport switch in the second film camera produced extra frames-remaining pulses and caused the control console frames-remaining indication to reach zero, four frames early. Also, the second film camera skipped one of the eight exposure positions on a filmstrip, accounting for the 21st frame loss. The total frame loss of 21 frames accounted for 0.3 percent frame loss for the mission, which was negligible.

The quality of most of the solar data obtained from the exposed film was excellent. The absence of truncated images on the film indicated that optical alignment of the slit in the slot baffle and on the film aperture remained correct. The focus and efficiency of the instrument were constant throughout the mission. Figure 12-16 illustrates a comparison of emission spectra obtained by the camera during the first manned period. The spectra shown represent 12 arc-sec from the limb on the solar disk exposed for 1.25 seconds and 4 arc-sec off

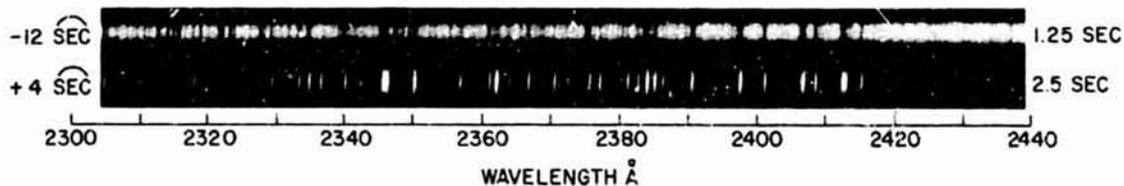


Figure 12-16.- Comparison of photospheric Fraunhofer and chromospheric emission spectra.

the disk (corona) exposed for 2.5 seconds in the 2300- to 2440-angstrom wavelength band. Representative photographs of an extreme ultraviolet monitor downlink transmission, obtained on Days 27 and 246, are shown in figure 12-17. The significant features seen from these photographs include high prominences on each limb and light areas in the center, where there is extreme ultraviolet activity.



Figure 12-17.- Experiment S082B extreme ultraviolet monitor downlink photograph.

A review of the first manned period film data revealed that exposures taken with the grating in the long-wavelength position were being overexposed when the preselected automatic mode exposure times were used. Daily flight plans were altered during the second manned period to take fewer long-wavelength exposures and to take exposures of very short duration in the long-wavelength band. This procedure obtained more desirable data with less expenditure of film, but required substitution of manual exposures for the automatic mode. An auxiliary timer supplied for the third manned period provided an automatic mode with shorter exposure times, thus decreasing the number of manual exposures required.

Following initial operation, the crew reported that the instrument video display on the control and display console was very faint. The crew was unable to adequately determine solar activity without the use of the video integration capability. With integration, the display

time was too short to allow visual study of details. The insufficient video signal level was due to the low sensitivity of the monitor. To correct the problem, an image persistence scope, a night vision pocket scope with long persistence phosphor, and a Polaroid SX70 camera were included for the last two manned periods. The image persistence scope retained the 0.03-second flash of the video integrate information long enough for the crew to view the Sun and its features. The Polaroid camera was used to record the video images on film, which gave the crew a permanent record of the integrated display. This allowed the crew to identify major changes in the solar surface. To correct a malfunction of the image persistence scope, a replacement scope was resupplied for the last manned period.

On Day 214, the crew noticed limb offset indication fluctuations on the television monitor when pointing the instrument slit on the solar limb. When the limb point was selected, the limb offset fluctuations exceeded the required accuracy. On Day 235, the crew reported seeing oscillations of the solar image on the television display when the white light display was acquired immediately after limb pointing. A test performed by the crew verified that the malfunction was caused by a low video signal level. Since the solar limb was within the pointing reference system failure region, use of the pointing reference system for limb pointing was discontinued for the remainder of the mission. The solar observatory pointing control was used for instrument limb pointing, allowing successful operation of the instrument to the conclusion of the mission.

### 12.1.7 Hydrogen Alpha

The hydrogen alpha telescopes provide a diffraction-limited image of the Sun in hydrogen alpha light (6562.8 angstroms). The telescopes view the entire solar disk or, by using the zoom feature, view specific targets-of-opportunity for further study by other solar observatory instruments.

The instruments, shown in figure 12-18, consist of two telescopes, a vidicon camera on each, a film camera on one, optics, a thermal control system, and associated electronics. A Cassegrain reflecting system with a parabolic primary and hyperbolic secondary collects and focuses the solar energy. Two refractive telecentric corrector elements correct the field off-axis and parallel the primary rays again. The heat rejection windows, an ultraviolet reflection filter, and an induced transmission filter reflect the visible and infrared energy. A solid-spaced Fabry-Perot etalon interference filter isolates the desired spectra from the other components. A beam splitter transmits the selected hydrogen alpha line through a fixed relay lens to a film camera, and reflects part of the selected hydrogen alpha line through a variable magnification zoom lens to the vidicon (beam splitter and film camera only for hydrogen alpha 1). The zoom lens assembly relays the Cassegrain image from the primary focal plane to the television vidicon focal plane and provides zoom capability by varying the field of view between 4.5 and 15.6 arc-min for the hydrogen alpha 1 telescope and between 7 and 35 arc-min for the hydrogen alpha 2 telescope. Movable crosshairs provide alignment reference with the other experiments. A vidicon provides the crew with a display for detecting and pointing at significant features. A 35-millimeter sequential film camera provides a permanent record of the pointing as well as yielding high quality photographs. The electronics provide control of the instrument from the control console and from the ground, and provide telemetry monitoring signals. A passive thermal control system maintains the proper temperatures.

The instruments successfully accomplished mission objectives by providing high-quality photographic and video images. The images were used by the crew to search the Sun for regions of scientific interest and to detect long term changes in solar structural phenomena. Solar observations by both the crew and scientists on the ground allowed international coordination of ground-based observations of solar events. The hydrogen alpha 1 film camera was operated extensively and obtained over 68,000 high-resolution photographs, using 5 film magazines. Each vidicon accumulated 1402 hours of operation during the mission. Real-time solar detail was displayed to the crew on the two control console video monitors and transmitted to the ground. The crew made a significant discovery when they observed that the hydrogen alpha displays provided a flare precursor. During solar observation, it was found that a general reorienting of sunspots, coupled with a heightening of activity in the hydrogen alpha wavelength, indicated that a solar flare was beginning.

Evaluation of the flight film indicated excellent optical quality. Figures 12-19 and 12-20 are examples of the photographs on Day 33 showing the solar disk in fine detail. Both vidicon cameras operated normally, displaying real-time solar detail to the crew on the control console video monitors, and providing downlinked television images for use in solar observation planning. The television images remained stable except for some degradation evident on hydrogen alpha 1 during the last month of the mission. Figures 12-21 and 12-22 are photographs of the downlinked television images.

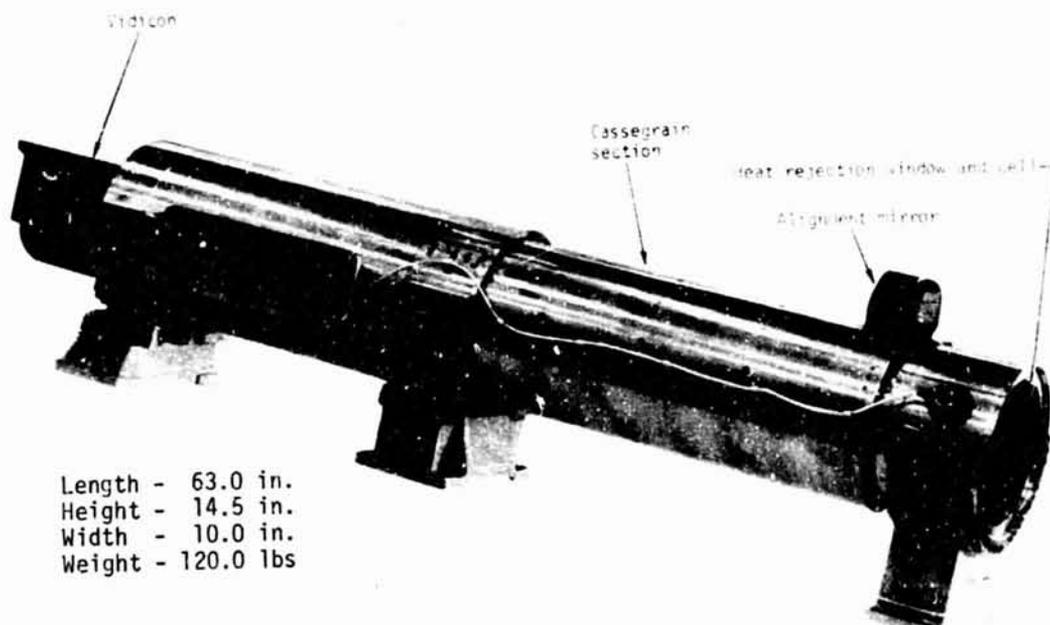
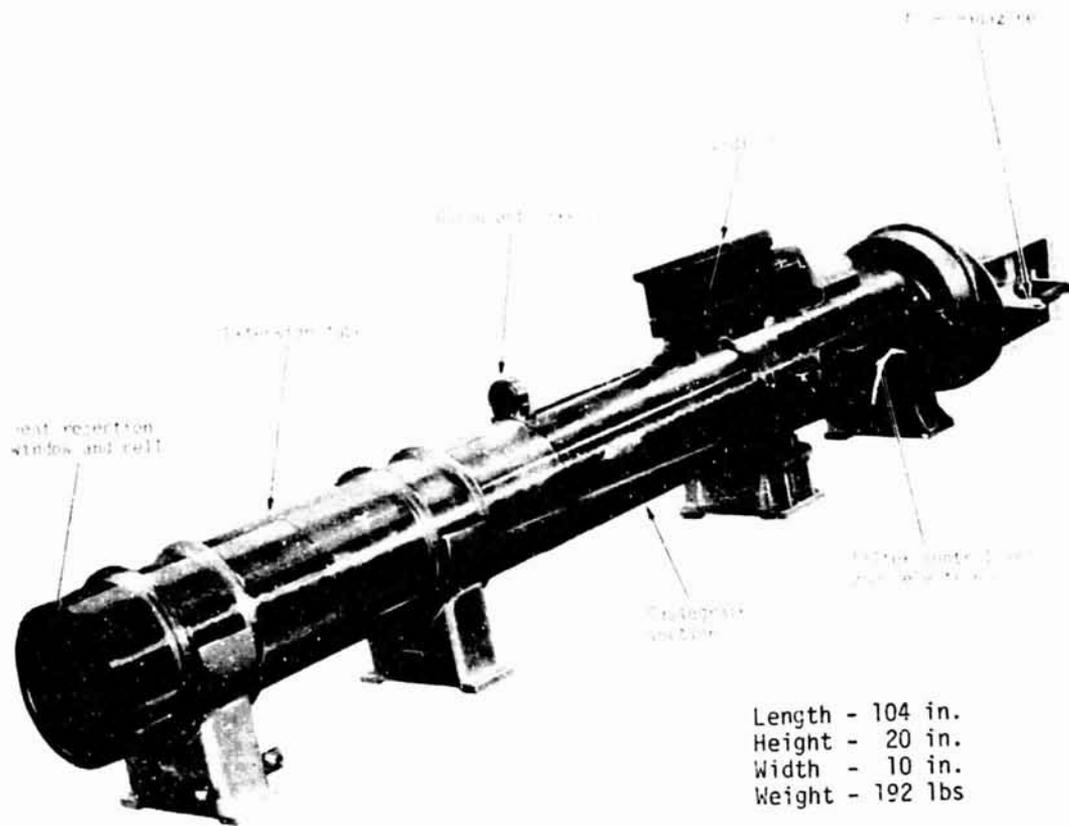


Figure 12-18.- Hydrogen alpha telescopes.

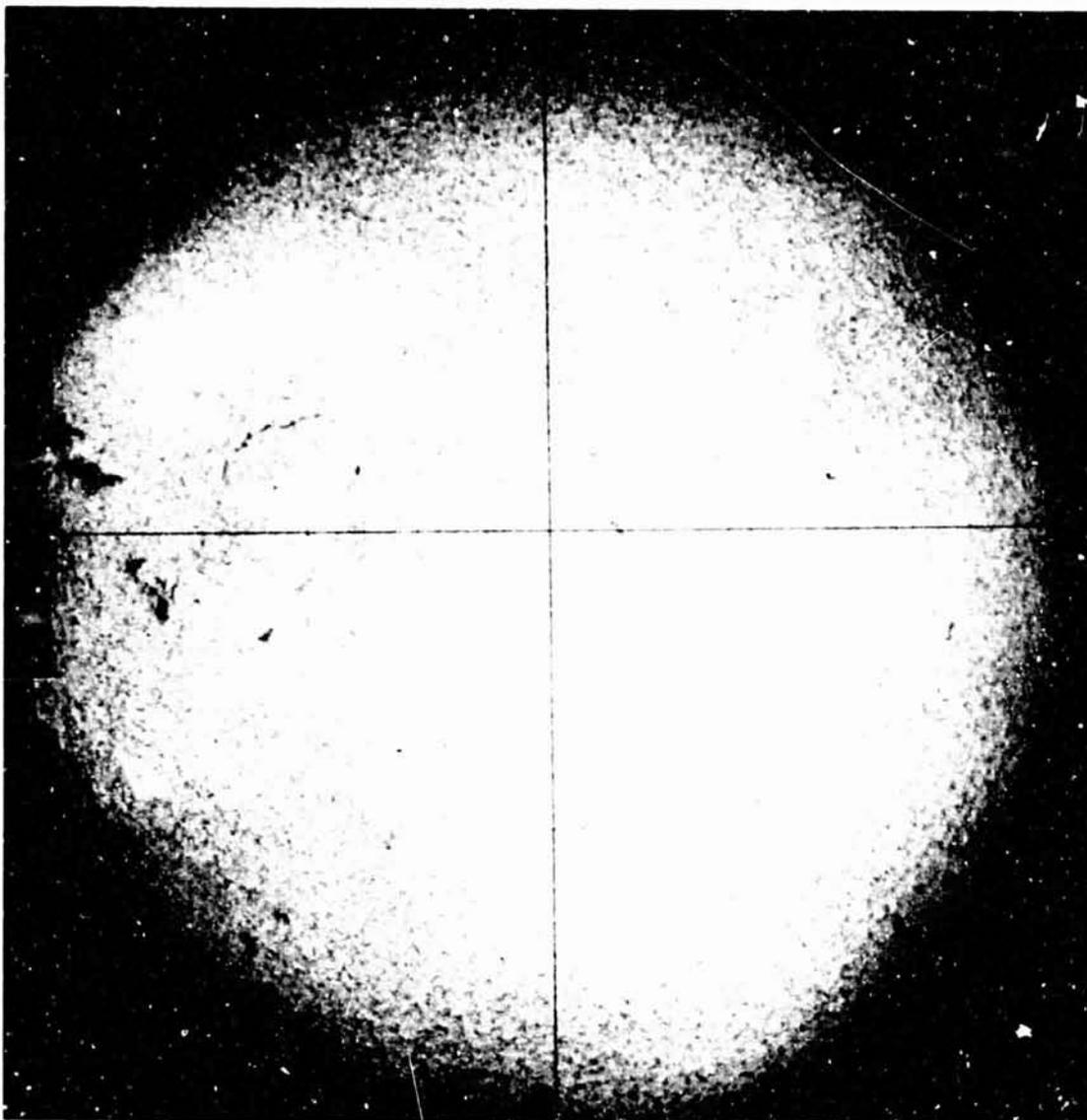


Figure 12-19.- Hydrogen alpha photograph of full solar disk.

On Day 248 the crew reported that the hydrogen alpha 1 film camera was inoperative. Reinitializing the system cleared the problem. On Day 249 the crew reported that the frames-remaining counter failed to decrement. The camera appeared to be operating, based on shutter telemetry and the crew's statement that the control console camera's operate light was performing properly. A daily comparison of the onboard frames-remaining indication and the ground estimate of frames remaining indicated that the frames-remaining counter, or the signal from the camera electronics to the counter, was operating intermittently. Preliminary evaluation of the film showed that operations were normal through approximately 80 percent of the first magazine used during the third manned period. After that time, film advance became intermittent, causing many overlapped pictures. Approximately 50 percent of the film in the second magazine was not exposed, and the exposed film contained overlapped images on approximately 20 percent of the exposures. The cause of the anomaly has not been determined.



Figure 12-20.- Hydrogen alpha solar flare.

## 12.2 ASTROPHYSICS

The astrophysics experiments investigated areas inside and outside our solar system. Nine experiments were dedicated to this cause. Two additional instruments were carried with the third crew for the explicit purpose of obtaining data on the Kohoutek 1973f comet.

Until recently, progress in astronomy was made by gradual theoretical and observational advances, using instruments associated with ground-based optical telescopes to measure the size, spatial relationship, energy distribution, and time changes of visible objects. With the advent of space flight, unexpected sources of background illumination have been detected in the ultraviolet range. Intense point sources and a diffuse background of X-rays have been discovered. Gamma ray and infrared radiation have been detected coming from the center of our galaxy. A number of other galaxies have been found to be unexpectedly bright in the ultraviolet and infrared ranges. These all suggest unusual processes are taking place.

Skylab provided an opportunity to perform a variety of survey type experiments with a much longer observing time than could be obtained on ballistic



Figure 12-21.- Hydrogen alpha 1 television.

be used by experiments because it was blocked by the parasol thermal shield. Those experiments that could not be adapted to the other airlock were taken outside the Saturn Workshop during extravehicular activity and deployed.

One extravehicular activity was devoted exclusively to studying the Sun and the comet with instruments taken outside. Extravehicular activity was also used to retrieve the data samples from experiments that were launched in their deployed configuration outside the Saturn Workshop.

Five experiments were devoted to studying objects beyond our solar system. Four experiments, plus the comet investigation, studied the Earth's outer atmosphere and the interplanetary medium. Four of these collected physical particles for return to Earth. The astrophysics experiments not only obtained quality of data never before returned from space, but helped in identifying the advantages and disadvantages of man-attended space observations and obtained information essential for planning future, more advanced instruments.

#### 12.2.1 Nuclear Emulsion (S009)

The nuclear emulsion experiment (S009) records the relative abundance and energy spectrum of heavy nuclei cosmic rays outside the Earth's atmosphere.

rockets, and with more flexibility because of a scientist's presence onboard. Larger and heavier instruments were used. Actual samples and film data were returned, which provided better resolution than data obtained from an unmanned satellite. Some experiments were mounted outside the Saturn Workshop, some inside. Others were extended outside the workshop and then retracted after gathering data. One was flown on the launch vehicle that carried the second Skylab crew into Earth orbit and required no crew participation.

Two scientific airlocks were provided in the workshop for those experiments that were to be extended outside, one on the +Z side and one on the -Z side. Each scientific airlock provided an approximately 8- by 8-inch opening to the space environment, yet maintained the normal shirt-sleeve environment for the crewman to remain in and operate the experiment (fig. 12-23). The one on the +Z side could not

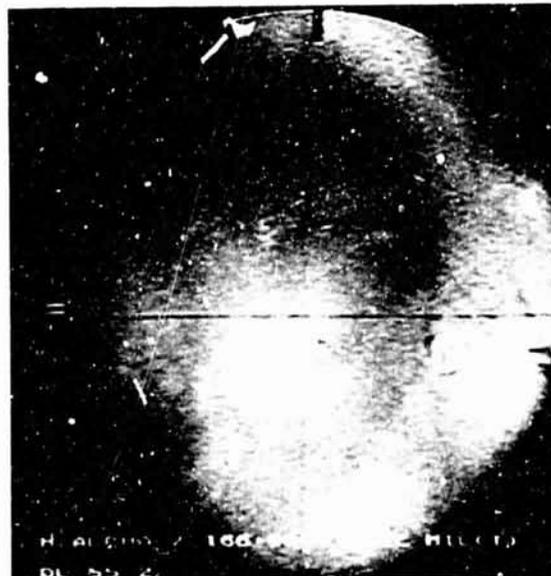


Figure 12-22.- Hydrogen alpha 2 television.

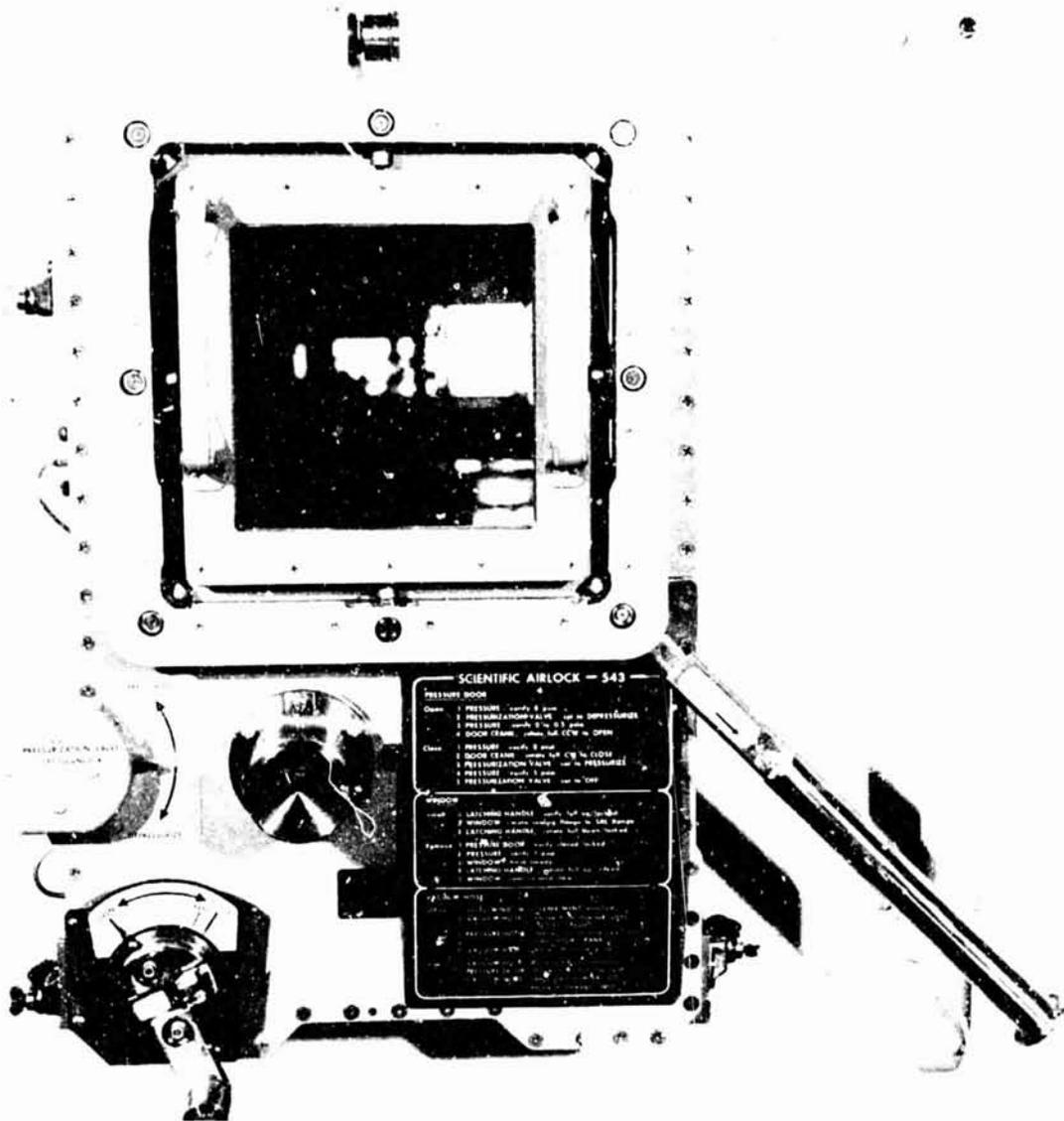


Figure 12-23.- Scientific airlock.

The apparatus (fig. 12-24) consists of two adjacent stacks of nuclear emulsion strips, mounted inside the docking adapter. The stacks are hinged together like the two sides of an open book and contain layers of different emulsion types. During exposure the "book" is open, allowing high energy particles which have passed through the wall to enter the front surface of both emulsion stacks. It is open only in the equatorial region between latitudes of 30 degrees north and 25 degrees south. Opening and closing are automatically controlled by an on-board timing signal. The experiment has a 22-degree field of view into deep space, perpendicular to the Skylab orbit. The emulsion is returned to Earth, peeled apart in numbered strips, developed, and scanned for particle tracks.

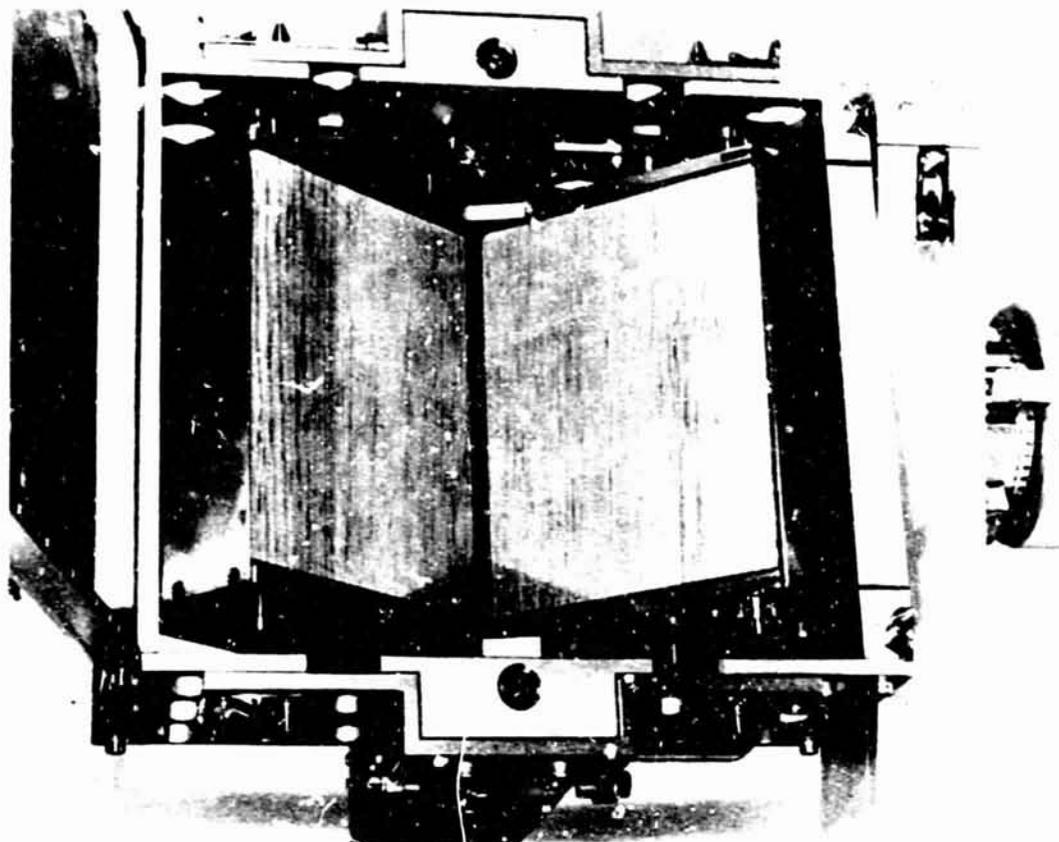


Figure 12-24.- Nuclear emulsion detector package.

The emulsion package was stowed in the workshop during launch. It was deployed in the docking adapter on Day 16. The motor which opens and closes the book failed on Day 28, and the package was deployed open until Day 37, when it was stowed for return to Earth. The experiment was not operated during the second manned period. A new motor and emulsion package were resupplied and installed by the third crew on Day 197, and normal performance of the experiment was restored. No data could be obtained from the emulsion package that was returned from the first manned period. The strips had fused together and could not be separated sufficiently. The motor failure on Day 28 caused the experiment to operate abnormally in that it remained open in the higher latitudes. Both emulsion packages were returned to Earth. In addition, Skylab pointing data were provided to help assess the times the experiment was pointed off its preferred direction, perpendicular to the orbital plane.

The heat damaged detector package was difficult to install and subsequently failed the motor. The mechanical tolerances of the detector package relative to the experiment housing were too tight, thereby causing additional loads on the motor when opening and closing the package. When the detector package was first installed in the S009 housing, the crewman commented that installation was difficult. This diagnosis was confirmed in ground tests in which the conditions were duplicated using a detector package having the same dimensions as the flight

package. When the crucial areas were machined down and life tests were conducted, that package proved capable of running in excess of mission requirements.

### 12.2.2 Gegenschein and Zodiacal Light (S073)

The gegenschein and zodiacal light experiment (S073) measures the brightness and polarization of the visible background of the sky above the Earth's atmosphere. No hardware was dedicated specifically to this experiment. It shared part of the hardware for the contamination measurement experiment (T027). Because both these experiments required knowledge of contamination and zodiacal light, the principal investigators collaborated. They combined their observations into a joint observing program using the T027 photometer system (12.4.8).

The measurements for the gegenschein and zodiacal light experiment were taken on the dark side of the orbit. The photometer scanned the various regions of the sky in a programmed sequence and recorded the light sensor data. Data were recorded both by telemetry and 16-millimeter photographs. The galactic photography took advantage of the dark night sky available from the Skylab orbit to detect the faintest outer limits of galaxies. Ground photography of this nature, even from the Mt. Palomar telescope, is limited by the brightness of the Earth's atmosphere at night.

During the first manned period, this experiment was operated on 6 different days and gathered data for 14 hours 37 minutes. During the second manned period, an anomaly occurred (12.4.8) that resulted in the photometer's being jettisoned overboard after being installed in the scientific airlock the first time for that period. No 16-millimeter data were obtained from that period because the camera was also jettisoned, but telemetry data were obtained for approximately 6 hours. Later during that period, the crew rigged the hardware of the coronagraph contamination measurement experiment (T025) and the 35-millimeter camera from the ultraviolet airglow horizon photography experiment (S063) and took seven exposures of the gegenschein. The success of these photographs led to the use of this equipment for similar photography during the third manned period.

During the third manned period, 96 exposures were made for this experiment using the new combination of equipment. Included as targets were zodiacal light, gegenschein, lunar libration, galaxies, the ecliptic pole, and Comet Kohoutek.

Returned data consisted of 16- and 35-millimeter photography and telemetry.

### 12.2.3 Galactic X-Ray Mapping (S150)

The galactic X-ray mapping experiment (S150) surveys the sky for faint X-ray sources to provide a catalog of those sources that have strengths from 0.2 to 10 keV. The experiment hardware is mounted in the instrument unit of a Saturn IB launch vehicle (fig. 12-25). It has five major hardware assemblies: the sensor, the gas supply system, the mounting and deployment bracket, the distributor, and the auxiliary storage and playback unit. Other needs of the experiment, such as electric power, are supplied by the instrument unit.

The sensor assembly uses a continuous-flow-gas proportional counter sub-assembly with pulse height analyzers. The output of the proportional counters is processed by the sensor's data processing system for input to the auxiliary storage and playback assembly and the instrument unit telemetry system. Two star sensors furnish location and orientation information to supplement that provided by the launch vehicle digital computer. Detectors determine the

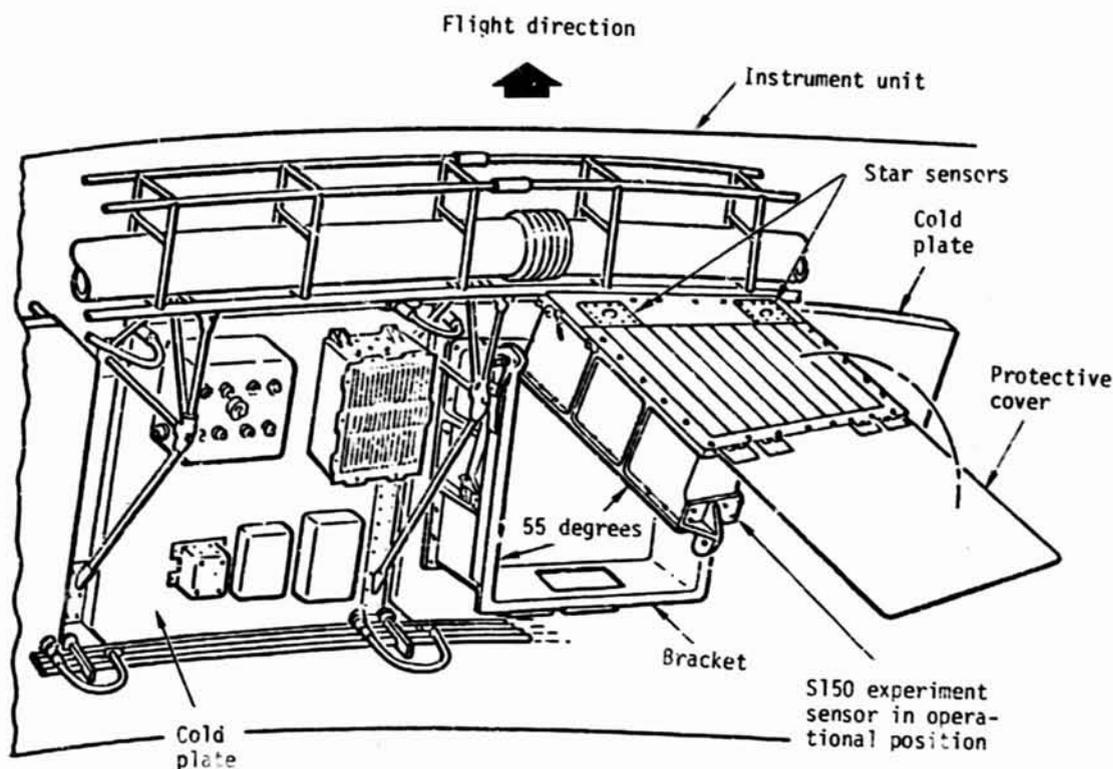


Figure 12-25.- Galactic X-ray mapping experiment sensor deployed.

location of X-ray sources to within 20 arc-min. Because of daylight X-ray fluorescence, no data below 0.7 keV are available during the daytime half of the orbit. Data are recorded onboard the vehicle and transmitted to Earth by telemetry.

The X-ray counters of the sensor are pressurized at about 14.5 psia. The argon-methane gas is a well-known X-ray counter gas, and it also provides the pressure required to keep the thin X-ray incident window properly positioned against its aluminum mesh support. This window, associated with the counter assembly, is made of polycarbonate plastic material (Kimfol) which allows passage of low energy X-rays. The plastic window is characteristically leaky and necessitates the use of a gas resupply system to replace the lost gas and maintain constant density in the counters. Collimators are located over the plastic window and gas counters.

The experiment hardware was flown on the launch vehicle that carried the second Skylab crew into Earth orbit on Day 76. The experiment began operating automatically 12 minutes after command and service module separation. It was planned to operate 265 minutes, almost three orbits. Because of a failure of part of the experiment hardware, however, it operated for only one orbit plus 11 minutes (103 minutes total).

The hardware functioned properly until a failure in the plastic window caused the pressure around the proportional counters to decay below 12 psia and the high voltage supply to turn itself off after 103 minutes of operation. The star sensor data and the reconstructed Sun angles from the launch vehicle digital

computer indicated the experiment was exposed to direct sunlight. The exposure to direct sunlight was a geometrical coincidence. The Sun stayed within the field of view for 13 minutes, a longer time than could be withstood by the thin plastic window. The chance of the programmed scan path approaching this close to the Sun (zero degree incident) is less than 1 in 10 for a random launch time.

The theory which best explains the increase in leakage rate of the plastic is that as the Sun moved across the sensor's field of view, specific areas of the plastic film were exposed to more intense solar radiation than other areas. This resulted in deformation of the holes inherent in the porous plastic material, or the creation of many new minute holes in the plastic. The leakage rate through the window was so great that the regulators could not supply enough gas to keep the pressure above the 12 psia that was required to preclude automatic shutdown of the high voltage supply. Before launch, the thin plastic film had ruptured during a vacuum chamber development test. The perforated aluminum mesh was then added to give the window additional strength.

Returned data consisted of telemetry from the experiment and from the digital computer memory. The latter provided data on attitude and orientation to the Sun.

#### 12.2.4 Ultraviolet Panorama (S183)

The ultraviolet panorama experiment (S183) photographs the color index of stellar objects in three bands: two bands approximately 635 angstroms wide, centered around wavelengths of 1878 and 2970 angstroms, and one band 360 angstroms wide, centered at 2560 angstroms.

The experiment equipment consists of two major assemblies: the spectrograph and the film carousel. The spectrograph produces the ultraviolet image of the desired target in the plane of a film plate and performs the photographing sequence. It is operated through the -2 scientific airlock and uses the S019 articulated mirror system. The film carousel provides a light-tight casing for 36 photographic plates used in the spectrograph. The carousel attaches with a pressure-tight seal to the spectrograph assembly during experiment operation. The operational configuration is shown in figure 12-26.

The spectrograph is a wide-field-of-view instrument which creates two almost-superimposed images of the selected star field on a single photographic plate. One image is centered in a spectral band about 1878 angstroms and the second image about 2970 angstroms. The exposure durations range from 20 seconds to 1260 seconds to allow two-bandpass photography of both bright and dim sources. An operational 16-millimeter data acquisition camera, attached to the spectrograph, simultaneously photographs the same star field in a 360-angstrom bandwidth centered around 2560 angstroms.

The experiment was operated during all three manned periods. The hardware and first set of film were launched aboard the Saturn Workshop. Because of the high temperature inside the workshop before deployment of the parasol thermal shield, it was thought that the films were damaged. A new carousel and a new 16-millimeter magazine were sent with the first crew. Thus two carousels and two 16-millimeter film magazines were available to this crew. The instrument was set up and operated on Day 20 and obtained three exposures. On Day 21, six exposures of four star fields were scheduled, but only two exposures were obtained because the carousel jammed. A malfunction procedure cleared the system, and the carousel was stowed for return to Earth. On Day 22, the crew took

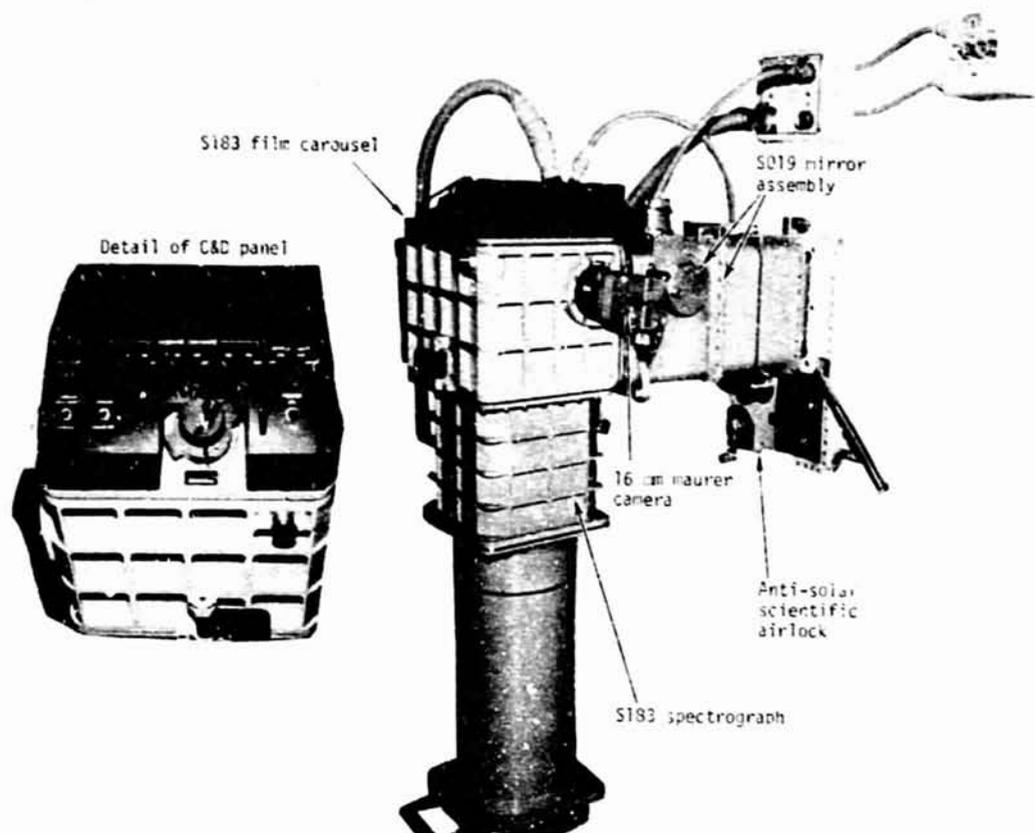


Figure 12-26.- Experiment S183 ultraviolet panorama instrument in operation.

photographs with the data acquisition camera only. On Day 37, the crew installed the carousel that was launched with the workshop and made seven exposures.

Although of scientific value, the quality of the photographs taken during the first manned period was not as good as expected. The spectrograph photograph plates exhibited loss of sensitivity and latent image fading. Exposures obtained early in the mission were more degraded than those taken later. The spectrograph plates were suspected of having been affected by outgassing of some chemical product used in the process of gold-coating the plastic film holders. Silver-coated film holders were provided in the carousels used during the third manned period. No carousel was sent with the second crew, thus no spectrograph pictures were made during that period. Photographs obtained with the data acquisition camera were out of focus and fogged. The degradation was suspected of being caused by the camera body and its mounting interface with the spectrograph. Different cameras were used during the second manned period to all. iate the problem.

All experiment photographs taken during the second manned period were taken with the 16-millimeter data acquisition camera. Four separate camera bodies were used during the period to investigate the degradation causes. The photographs were still out of focus, which meant the problem had to be on the spectrograph side of the mounting interface.

Two carousels and one 16-millimeter film magazine were resupplied for the third manned period, along with a new mounting fixture and optics for the data acquisition camera. The two carousels provided additional film plates for obtaining data on Comet Kohoutek. A total of 43 plates were exposed during this period, including 6 of Comet Kohoutek. Both carousels had various problems with indexing throughout this period. Broken glass from a film plate caused jamming within one carousel. The data acquisition camera film magazine jammed on Day 253, which resulted in a blown fuse in the spectrograph. Because the fuse was inaccessible, the crewman built a jumper cable to bypass the fuse and restored operation. The data acquisition camera was not used thereafter because there was no more 16-millimeter film for ultraviolet photography.

Carousels with 13 exposed plates were returned from the first manned period and with 43 plates from the third. Magazines containing 15, 12, and 35 exposed 16-millimeter frames were returned from the first, second, and third manned periods, respectively. In addition, the ultraviolet stellar astronomy instrument provided 29 spectrograph frames of data for this experiment.

The problems with the carousels, involving jamming, improper indexing, and film plate protrusions, occurred on six separate occasions: once during the first manned period and five times during the third. No carousels were used during the second manned period. By using malfunction procedures and by consulting with the experiment representatives, the crew was successful in conducting ultraviolet panorama experiment operations.

The complexity of the experiment hardware makes it susceptible to interrupted performance. The carousel drive mechanism has a slip clutch to protect the motor if the carousel jams. The slip clutch design permits the carousel film plate number indicator to advance, even though the carousel is not moving. This leads to improper indexing and the loss of synchronization between the actual film plate and the film plate indicator. Because of design, whenever the carousel is removed from the spectrograph and is not indexed to its true 01 position, a film plate is pulled partially from the carousel. Failure of the crewman to reindex the frame indicators to the 01 position when removing or installing the carousel on the spectrograph further contributes to the problem of improper indexing. The causes of the remaining problems cannot presently be determined.

#### 12.2.5 Transuranic Cosmic Rays (S228)

The transuranic cosmic rays experiment (S228) provides the means to obtain detailed knowledge of the relative abundances of nuclei with atomic numbers greater than 26 in the cosmic radiation, and to observe and identify many transuranic nuclei.

The experiment uses plastic detectors mounted in the workshop, where they are exposed to cosmic radiation. The cosmic rays penetrate the workshop walls, then penetrate the detector packages, streaking the plastic sheets within. Some of the cosmic rays stop within the detectors, and others pass through them. The hardware consists of 2 harness assemblies, each containing 18 detector modules. Each detector module contains 32 sheets of 7 by 9 by 0.010 inch thick Lexan polycarbonate wrapped in aluminum foil tape. After being exposed to the cosmic rays, the detector modules are removed from the harness assembly by the crewman, stowed in the command module, and returned to Earth for analysis.

The hardware was stowed aboard the workshop for launch. It was removed from stowage and deployed on Day 16. The crewman attached the harness assemblies

between the floors of the workshop, using Velcro to attach them to the triangular grids. The two harness assemblies are located near the workshop outer wall and suspended between floors near the wardroom compartment, as shown in figure 12-27.

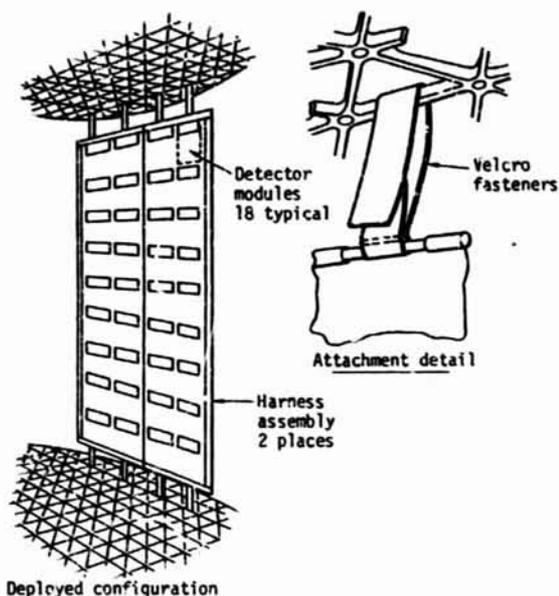


Figure 12-27.- Transuranic cosmic rays experiment deployed configuration.

The experiment hardware is simple and performed as designed. Deploying the harness assemblies as well as collecting the exposed detector modules was an easy task for the crewman. No problems were encountered.

#### 12.2.6 Magnetospheric Particle Composition (S230)

The magnetospheric particle composition experiment (S230) provides the means to collect and measure the fluxes and composition of ions and trapped particles which precipitate from the magnetosphere.

It uses a foil collection technique to capture the particles. Particles implant themselves in aluminum and platinum foils which are mounted on the outside of the workshop and exposed to the radiation environment. The foils are returned to Earth and the implanted gases analyzed in a laboratory.

The equipment consists of collector foils mounted on a flexible backing material. These collectors are mounted in the form of four cuffs on the airlock deployment assembly before launch, as shown in figure 12-29. Two inner cuffs are mounted adjacent to each other under the extravehicular activity handrail and the outer two are mounted over these. The two outer collectors are 21.5 by 16.5 inches, and the two inner collectors are 21.25 by 15.25 inches. All collectors consist

The 36 detector modules, depicted in figure 12-28, are exposed to cosmic rays that penetrate the walls of the workshop. One detector module was returned to Earth on Day 135 after having been exposed for 116 days. Thirty-four detector modules were returned to Earth on Day 27 after being exposed for 251 days.

An additional detector module was launched with the third crew. It was deployed outside Skylab on Day 193 during an extravehicular activity. The module was attached to an existing clipboard located on a handrail. This module collected data on cosmic rays that did not have to penetrate the workshop wall. The module was retrieved on an extravehicular activity on Day 266 and was returned to Earth on Day 271. On Day 267, the remaining detector module was moved from the workshop to the docking adapter and deployed there. This detector module was left behind at the end of the third manned period and is to be retrieved if there is a revisit to Skylab.

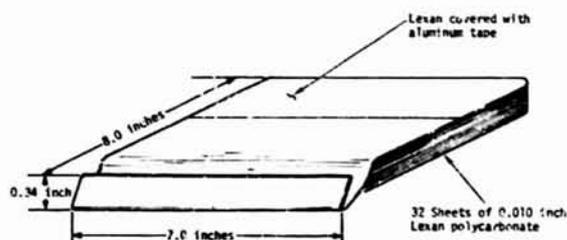


Figure 12-28.- Transuranic cosmic rays detector module.

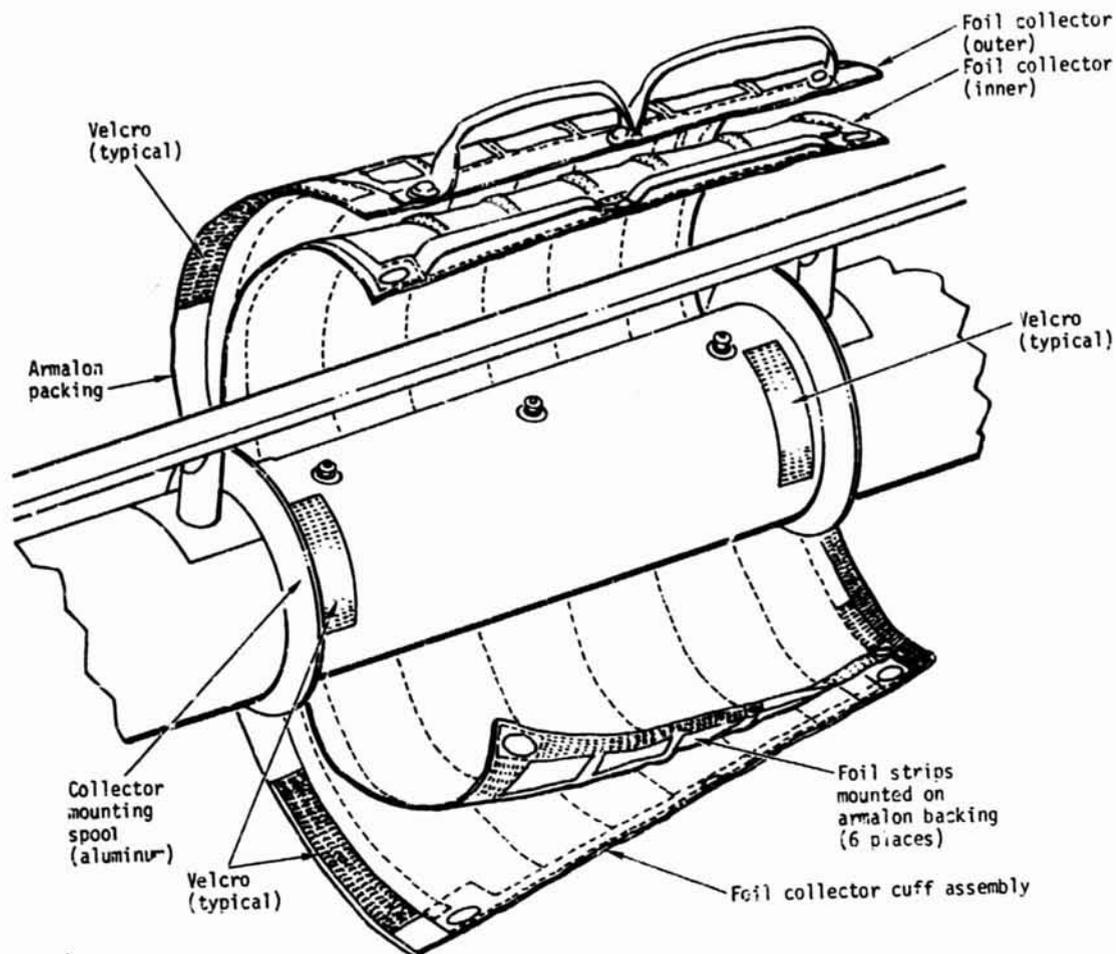


Figure 12-29.- Magnetospheric particle composition experiment collector cuff configuration.

of a backing layer of Armalon supporting the foils which serve as the collecting surface. The foils are attached to the Armalon by adhesive tape. Each collector has a fabric handle used for the extravehicular activity operations.

The outer collectors were uncovered to start collecting particles when the shroud was jettisoned, approximately 15 minutes after launch of the Saturn Workshop. The outer collectors were retrieved on Day 85 during extravehicular activity, thus exposing the inner collectors. One inner collector was retrieved on Day 132, and the three collectors were returned to Earth on Day 135.

Because of surface contamination deposited on the two outer collectors during flyaround and docking of the first two crews, a new collector was carried with the third crew. This collector was installed on the aft spool on Day 193. The last two collectors were retrieved on Day 266 and returned to Earth on Day 271.

Except for retrieval of the collectors and installation of one collector during extravehicular activities, the experiment was completely passive. Some of the collectors were exposed during docking, undocking, and flyaround by the command and service module. These collectors contain useful data but also have surface contaminants deposited on the foils which may complicate data analysis.

The new collector that was installed was damaged subsequent to retrieval. It was tethered inside the airlock, and when repressurization commenced, the intruding air shredded approximately 2 percent of the collector.

#### 12.2.7 Cometary Physics

Comet Kohoutek is named for Dr. Lubos Kohoutek, an astronomer at West Germany's Hamburg Observatory who discovered it in March 1973. It is officially designated 1973f, the sixth comet discovered in 1973.

Opportunity for Comet Observations.- The early discovery of the comet gave scientists an unprecedented length of time to prepare for studying it. Most new comets give scientists only 1 or 2 month's notice. Realizing the unique opportunity to observe a new comet from above the atmosphere, the Skylab Program Director requested the Marshall Space Flight Center and the Johnson Space Center to perform a compatibility assessment for conducting a comet observation program during the third manned period. National Aeronautics and Space Administration scientists developed a plan to observe the comet from X-ray through microwave frequencies by means of ground observatories, aircraft, balloons, rockets, and satellites. The observing program was to use to the fullest extent the instruments already onboard Skylab and other instruments that could be available in time to be carried to Skylab by the third crew. Skylab capabilities included long term viewing, near-perihelion viewing, immediate human response to sudden comet changes, and a wide range of payload instrumentation, all above the atmosphere.

Integrated Viewing Program.- The comet's position relative to the Sun would be constantly changing (fig. 12-30). A viewing program therefore had to consider the Skylab instruments' capabilities for observing the comet at different angles from the Sun, at different brightness levels, and with different available exposure times. The capability of the vehicle and crew to use those instruments in the required time frame had to be considered.

The program defined four methods of viewing the comet: through the scientific airlock, through the various Skylab windows with hand-held cameras, with the solar observatory telescopes, and carrying instruments outside during extravehicular activity. When the comet was in the direction of the Sun, the solar observatory telescopes were ideal, as they were normally pointed in that direction. The scientific airlock that could be used was on the side of the workshop away from the Sun. This required the viewing direction of instruments using it to be changed up to 180 degrees, depending on the comet's location. Rolling the vehicle 180 degrees would have placed it in an undesirable orientation. The articulated mirror system from the ultraviolet stellar astronomy experiment was used to obtain a 90-degree angle, and then the vehicle maneuvered up to 90 degrees to view the comet. The various windows were used for photographing the comet at times of opportunity when the comet could be seen through them without maneuvering the vehicle. Viewing during extravehicular activity allowed the crewman to have a large field of view and to use the solar arrays or an instrument occulting disk to occult the Sun.

Experiment Hardware Selection.- All Skylab instruments capable of recording images or electromagnetic spectra were investigated. The Earth observation instruments were immediately eliminated. Their cameras and detectors were too limited in resolution and sensitivity for this application. In addition, their location would require an undesirable vehicle orientation for their use. Five

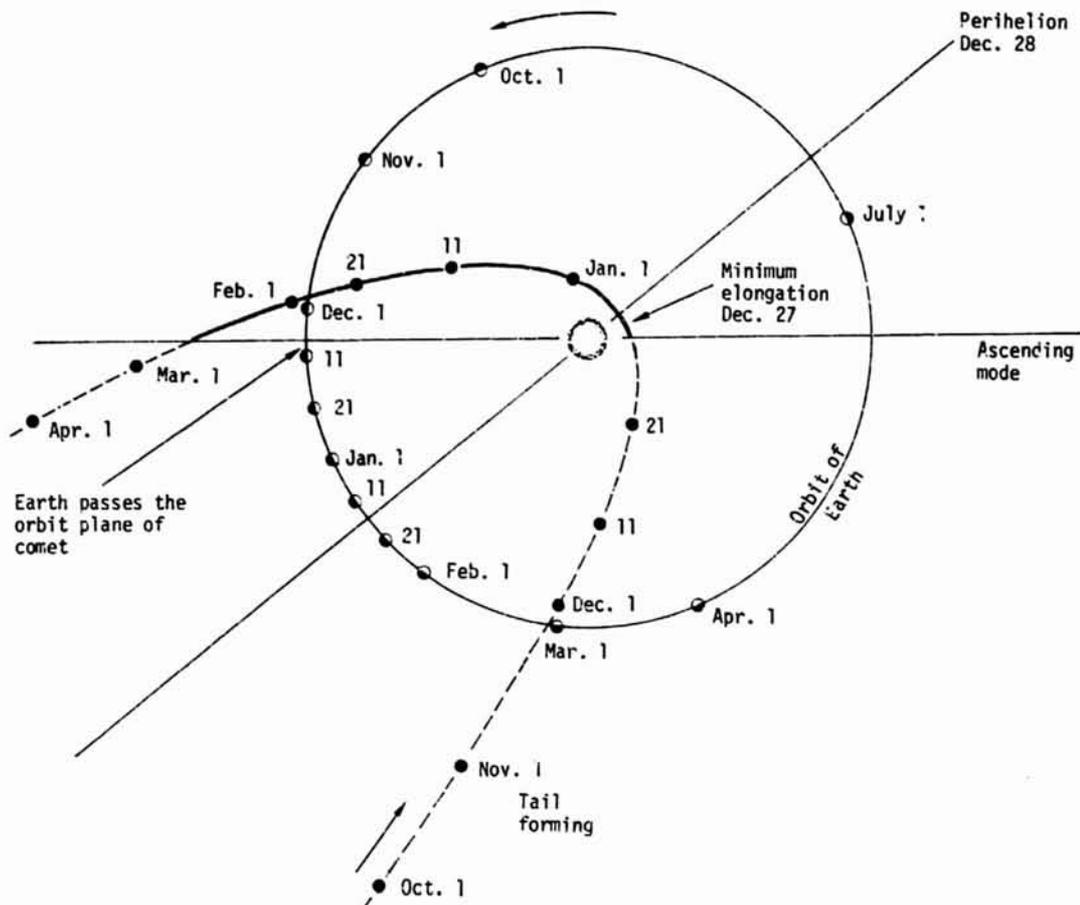


Figure 12-30.- Orbit of Comet Kohoutek (1973f), 1973 and 1974.

instruments were selected to view the comet through the scientific airlock. These instruments used the articulated mirror system to avoid extreme orientation changes.

Early in the viewing program definition the solar observatory instruments were chosen to view the comet when it was closest to the Sun. Assessment revealed that using these instruments to view the comet when it was within 10 degrees of the Sun during pre- and post-perihelion would have a negligible effect on the Skylab vehicle's systems. Therefore, near perihelion, when scientific interest in the comet was the greatest, the amount of comet viewing with these instruments was dictated by crew availability and priority tradeoffs with other mission objectives. Six solar observatory instruments were selected to view the comet. Instruments from five other experiments already onboard were used, and two new experiments, the far ultraviolet electronographic camera experiment (S201) and Kohoutek photometric photography (S233), were developed for comet observations.

Extravehicular activities for comet observations were limited to two, one at pre-perihelion and one at post-perihelion. There was one instrument onboard for coronagraph contamination measurements (T025), designed for detecting particles around Skylab, that could be effectively used. Another instrument, the far ultraviolet electronographic camera (S201), specifically carried to Skylab for comet viewing, could also be carried outside and operated by maneuvering Skylab

so the solar arrays would occult the Sun. These two instruments were selected to be used during extravehicular activities.

Two instruments were used for hand-held photography. One onboard Nikon camera was dedicated to Kohoutek photometric photography (experiment S233), and was used to take daily photographic measurements of the comet's brightness. Occasionally, the ultraviolet airglow horizon photography (S063) instrument, which was normally used in the scientific airlock, was also used through the window as the comet became a target-of-opportunity. Observations with hand-held instruments were constrained to periods when the comet was in the field of view of a particular window and not occulted by protruding external members of the Skylab vehicle. All windows in Skylab filtered out the ultraviolet wavelengths.

Existing Experiment Hardware.- The name and number of the existing experiment hardware used to view Comet Kohoutek and the physics that the hardware investigated are:

- a. Ultraviolet stellar astronomy (S019)
  1. The composition of the comet.
  2. The astrophysical processes which occur in the comet as it interacts with the solar radiation and solar wind.
  3. The overall temporal evolution of the comet.
- b. Ultraviolet airglow horizon photography (S063)
  1. The spatial and temporal variation of the selected atomic and molecular constituents.
  2. The degree of linear polarization of the coma and tail.
- c. Gegenschein and zodiacal light (S073)
 

Distribution of comet particles.
- d. Ultraviolet panorama (S183)
 

Production rates, spatial distribution, and lifetime of hydroxol ions in the coma to determine the amount of water, ice, or snow content.
- e. Coronagraph contamination measurements (T025)
  1. Particulate production rates and spatial distribution.
  2. Production and distribution of hydroxol, cyanide, carbon, sodium, ammonia, and carbon monoxide molecular components of the coma and tail.

The above instruments were all capable of operating through the scientific airlock. However, the coronagraph contamination measurements instrument was operated only during extravehicular activity and the ultraviolet airglow horizon photography instrument was also used for hand-held photography through the windows. The solar observatory instruments used and the physics that they investigated are as follows:

- a. White light coronagraph (S052)
  1. Structural density and its evolution over a period of several weeks.
  2. Tail mass changes near perihelion passage.

- b. X-ray spectrograph (S054)
  - Total mass density of medium weight elements such as carbon, nitrogen, and oxygen along the line of sight.
- c. Ultraviolet scanning polychromator spectroheliometer (S055A)
  - Radiance of the hydrogen halo.
- d. X-ray telescope (SC56)
  - Soft X-ray fluorescence of materials.
- e. Extreme ultraviolet spectroheliograph (S082A)
  - 1. Chemical composition and the ratio of helium to hydrogen.
  - 2. Effects of solar wind and solar radiation on comets.
- f. Spectrograph and extreme ultraviolet monitor (S082B)
  - Metallic, diatomic, and polyatomic emission lines for unique data on chemical composition.

New Experiment Hardware.- Two new pieces of experiment hardware were carried with the third crew to view the comet. Their titles and the physics they investigated are:

- a. Far ultraviolet electronographic camera (S201)
  - 1. Growth and structure of the hydrogen halo with heliocentric distance.
  - 2. The atomic oxygen production rate and distribution.

The S201 hardware was used both in the scientific airlock and during extravehicular activity.
- b. Kohoutek photometric photography (S233)
  - 1. Calibrated photometric data from defocused photographs of starfields and the comet's coma.
  - 2. A photographic history of the comet.

The experiment hardware was an operational 35-millimeter Nikon camera using a 55-millimeter focal length lens. It took pictures through three different Skylab windows, twice each day when possible.

Observations through the scientific airlock began on Day 196 and ended on Day 264. All observations but one through this airlock were made with four instruments: the ultraviolet stellar astronomy, ultraviolet airglow horizon photography, and ultraviolet panorama instruments, and the far ultraviolet electronographic camera. On one occasion, the gegenschein and zodiacal light instrument photographed the edge-on view of the comet plane. Only one instrument could use the scientific airlock at a given time.

Because the solar observatory instruments were designed to view the Sun, they were less sensitive to light than other instruments. They were therefore initially constrained to be operated between Days 215 and 242. They were actually operated between Days 220 and 238.

Extravehicular activities for comet viewing occurred on Days 226 and 230. These were 2 days on each side of the minimum elongation angle, not at perihelion, which occurred on Day 229.

Figure 12-31 shows the different days the various instruments viewed Kohoutek. Returned data consisted of various types of film and film plates, television recordings, telemetry, and crew sketches.

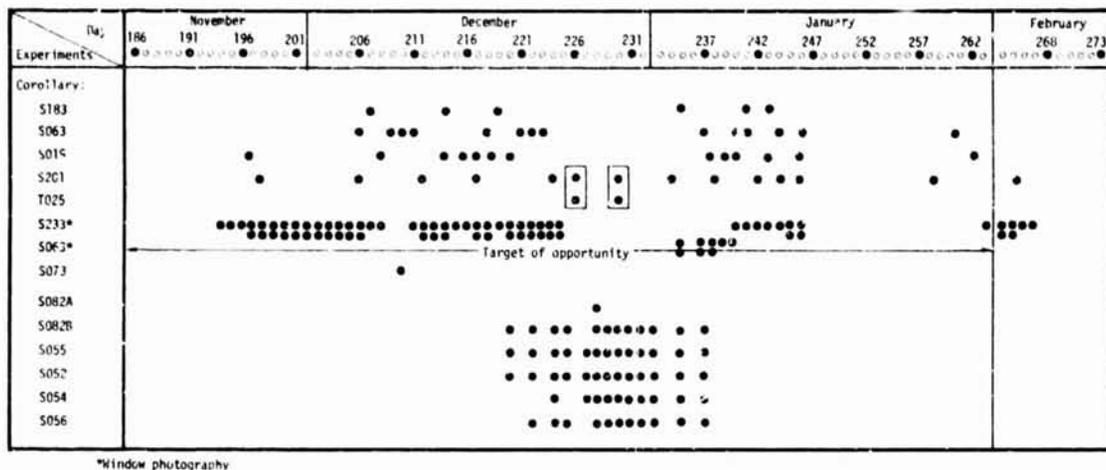


Figure 12-31.- Kohoutek experiment viewing.

### 12.3 MATERIALS SCIENCE AND MANUFACTURING IN SPACE

Even though gravity and atmosphere are necessary for man's normal existence on Earth, they have kept man from perfecting the end products of many manufacturing processes. The special conditions of virtual weightlessness and vacuum intrinsic to orbital flight make it possible to perform operations in materials processing that would be impossible or prohibitively difficult on Earth. Melting and mixing without the contaminating effects of containers, the suppression of convection and buoyancy in liquids and molten material, the control of voids, and the ability to use electrostatic and magnetic forces otherwise masked by gravity open the way to a new knowledge of material properties and processes, and may ultimately lead to the development of valuable new products for use on Earth. These potential products include composite structural materials possessing highly specialized physical properties; large, nearly perfect crystals possessing valuable electrical and optical properties; and new vaccines that can not be produced by conventional means.

Various methods for obtaining low gravity were used as precursors to Skylab to verify study results and facility designs. These ranged from laboratory tests, in which 1 second of low gravity could be obtained, to aircraft trajectories and sounding rockets, which afforded minutes of low gravity, to the Apollo lunar program, where several days were obtainable. All of these methods have some undesirable characteristics; nevertheless, they accomplished their purposes.

The original interest in manufacturing processes in space concerned the properties of welding in zero gravity for the purpose of assembling large structures in space, an early concept for the construction and maintenance of large orbital spacecraft. Electron beam welding in space was proposed a decade ago after a year's development of this type of welder. It was approved for flight in 1966. As the interest and emphasis on materials research increased, a common processing facility was designed to accommodate different types of materials processes.

Accommodating the materials processing facility aboard Skylab required consideration of the mass and volume of the physical unit and working volume for the crewman to operate the facility and remove and install the samples. An access to space vacuum from the work chamber had to be provided. Any condition that might cause an artificial gravity or exert a force on the molten metal had to be considered also, and perhaps controlled. Normal electrical support and lighting were also required.

The materials processing in space experiments probed the feasibility of several specific processes and acquired data for selecting the most promising processes and products for future facilities. First, the facility approach as provided was to be evaluated. Second was validation of the electron beam as a source for heat and welding on two experiments. Next, the exothermic brazing process was investigated with one experiment containing four samples. Eleven separate experiments used a common furnace that mounted inside the work chamber where 54 samples involving material phase changes were processed. The investigations were concluded by the performance of a set of experiments on flammability. About 40 samples were ignited in the work chamber and allowed either to burn freely or be quenched. Quenching was accomplished by evacuating the chamber or spraying water on the sample.

#### 12.3.1 Materials Processing Facility (M512)

The materials processing facility (M512) tests and demonstrates a facility approach for future materials process experimentation in space. It also provides a basic apparatus and a common Saturn Workshop interface for a group of metallic and nonmetallic materials experiments. The facility (fig. 12-32) is integrated into the docking adapter and consists of a vacuum work chamber with associated mechanical and electrical controls. The vacuum chamber is a 16-inch sphere with a hinged access hatch. It is connected to the space environment by a 4-inch-diameter, 3-foot-long line containing two manual valves in series. The chamber contains an electron beam subsystem which operates normally at 20 kilovolts and 80 milliamperes. It has focusing and deflection coils that are operated from the control panel. Electric power for the electron beam and exothermic experiments is supplied by a self-contained battery. Other experiments performed in the facility obtain their power from the laboratory power system. A cylindrical well accommodates a small electric furnace used in another series of experiments. A mounting fixture is incorporated to accommodate each experiment module in turn. The fixture also doubles as a heat sink with a predetermined and calibrated thermal impedance. Ports for a floodlight, a 16-millimeter data acquisition camera, a vacuum cleaner, and a water spray are provided in the work chamber.

The control panel (fig. 12-33) contains the gages to monitor the pressure in the chamber, the voltage and current of the electron beam gun, and certain temperatures. In addition, switches and potentiometers located here operate and control the individual experiments except the multipurpose electric furnace series. This series was approved late in the program (June 1972), and has its own controls. It uses the work chamber only as a location and vacuum source for its furnace. The facility has electrical, mechanical, and other integration interfaces with the docking adapter. Beyond this, it is a self-contained facility for the crewmen to use to perform the different materials processing experiments.

The facility was operated during all three manned periods. The metals melting, exothermic brazing, and sphere forming experiments were performed during the first period; the multipurpose electric furnace series of experiments was

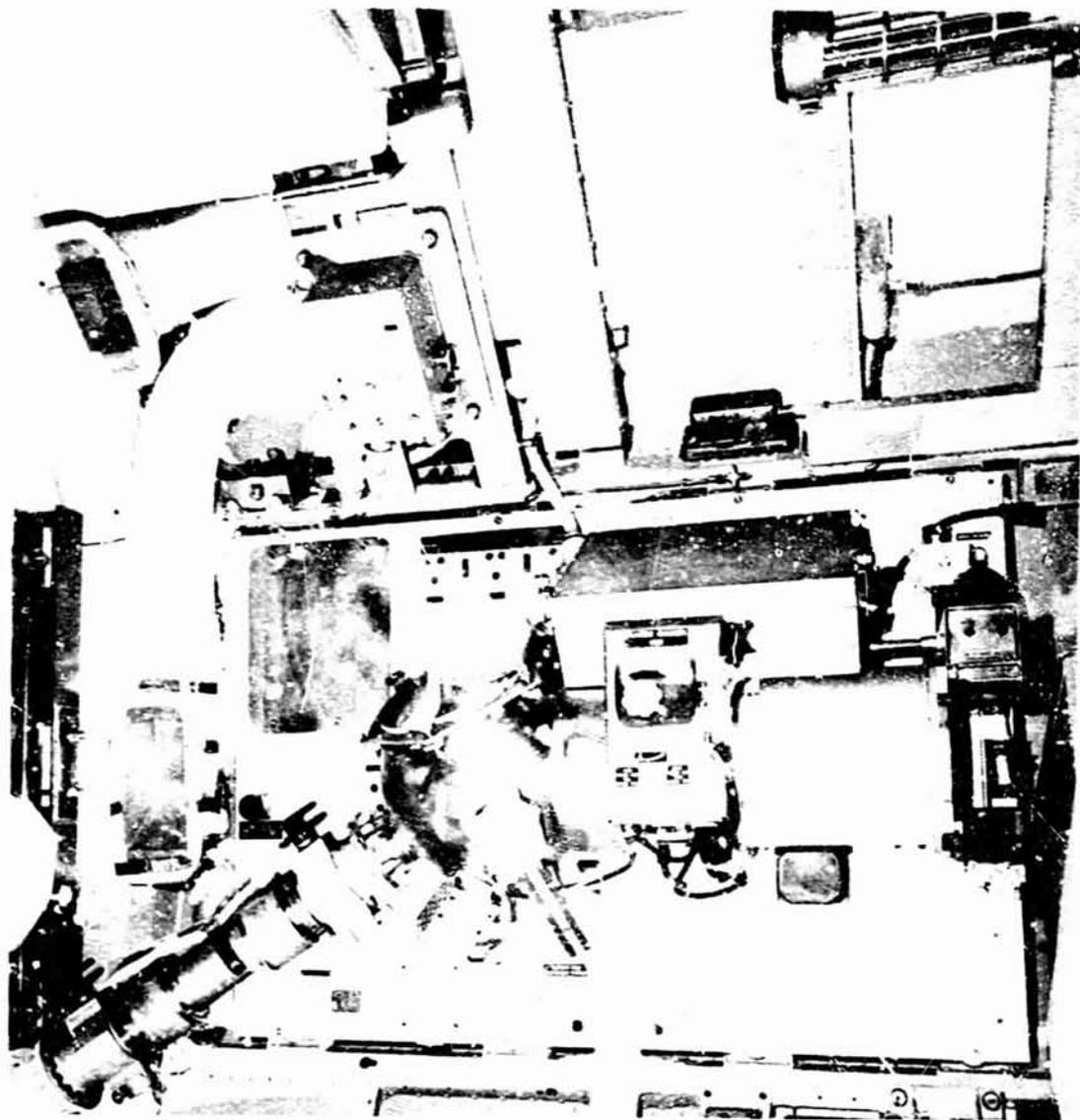


Figure 12-32.- Materials processing in space facility installed in docking adapter.

performed during the second and third; and the zero gravity flammability experiment was performed during the third. All experiments except the zero gravity flammability experiment required a reduced pressure in the facility (as low as  $1 \times 10^{-4}$  torr) while being performed. This was obtained by venting the work chamber to the outside of the workshop where the ambient pressure is approximately  $2 \times 10^{-8}$  torr.

The facility approach demonstrated by the materials processing in space experiment worked well. The facility provided the necessary apparatus for performing experiments that made significant progress in materials science.

Metals Melting (M551).- The metals melting experiment studies the behavior of molten metals at low acceleration levels, examines the characteristics of structures formed in metals that are melted and rapidly solidified in low

- |   |                                      |
|---|--------------------------------------|
| A. Facility work chamber hatch          | C. Facility work chamber             |
| B. Facility control panel               | E. Experiment M518 furnace installed |
| C. Electron beam filament chamber valve | F. Experiment M518 control panel     |

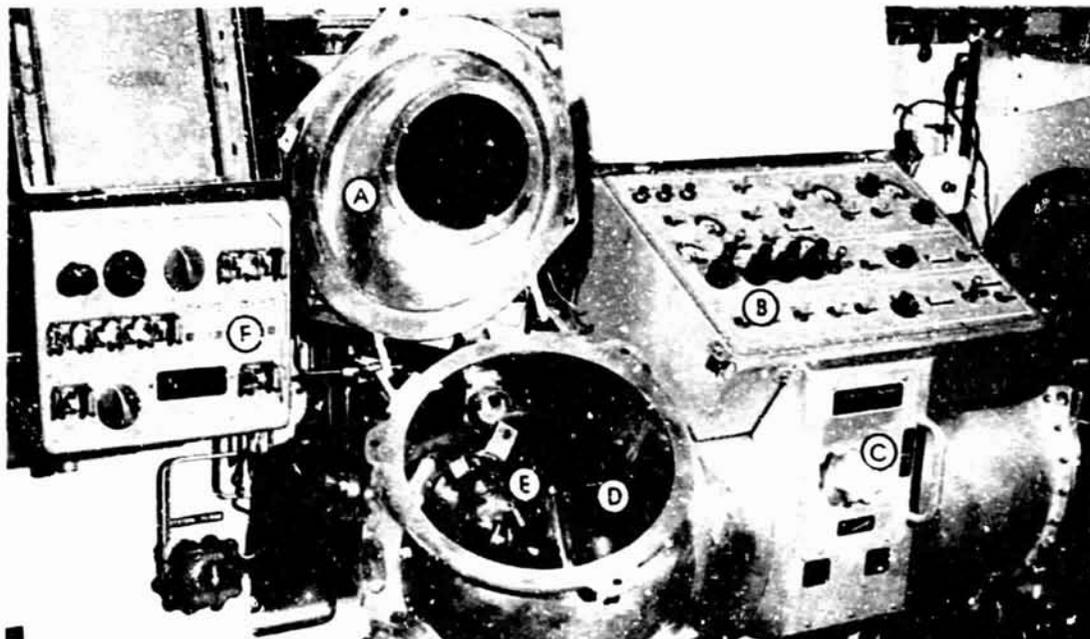


Figure 12-33.- Materials processing in space facility components.

gravity, and tests the possibility of joining metals by electron beam welding in space.

Three metal disks (stainless steel, aluminum alloy, and pure tantalum) are partially melted by the electron beam. The stainless steel and aluminum samples are graduated in thickness from 0.025 to 0.25 inch. The tantalum sample is graduated in thickness from 0.017 to 0.062 inch. All samples are 6.5 inches in diameter. The graduated thicknesses accommodate different operational aspects of cutting, complete penetration, partial penetration, and dwell.

The experiment operation requires mounting a sample disk to the drive motor and attaching this assembly to the heat sink inside the work chamber (fig. 12-34). The motor rotates the disk in front of the electron beam at a linear rate of 35 in./min. The beam is initially aligned on a tungsten "target" which is embedded in the sample. The disk is then rotated and the metal melted to some depth, depending on the thickness, along the beam's track. The molten metal at the center of the track is superheated, and there is a steep temperature gradient from the center to the edge of the molten metal pool. As the disk moves through the beam, the melted metal left behind solidifies very rapidly because the rest of the plate serves as an effective heat sink. Following this "welding" operation, the sample disk is advanced to a prescribed position and the beam allowed to impinge on one spot (dwell), without sample rotation, for a predetermined period of time ranging from 15 to 45 seconds.

- |                      |                           |
|----------------------|---------------------------|
| A. M512 work chamber | D. M551 electrical cable  |
| B. M551 work sample  | E. M512 electron beam gun |
| C. M551 motor        | F. M512 viewing mirror    |



Figure 12-34.- Metals melting experiment installed in work chamber.

The three samples were processed on Day 30. All hardware performed as expected. The three samples were returned to Earth along with 200 feet of 16-millimeter S0168 color film and the crewman's comments relating to the experiment performance. Figure 12-35 is a picture of the aluminum returned sample.



Figure 12-35.- Metals melting experiment returned sample.

Exothermic Brazing (M552).- The exothermic brazing experiment tests and demonstrates a method of brazing components for assembly, repair, and maintenance operations in space. It further studies surface wetting and capillary flow effects in molten metals in a weightless environment.

Four exothermic brazing samples are used. Each sample is a metal tube 0.75 inch in diameter by 3.69 inches long with a 0.049 inch wall thickness. Two samples are stainless steel and two are nickel. A slit is cut around the perimeter of the tube, leaving enough of the perimeter uncut to provide support to the tube on each side of the slit. The slit simulates two separate tubes butted together. Surrounding

the simulated joint is a stainless steel or nickel sleeve to be brazed to the tube. The braze alloy (silver-copper-lithium) is in the form of two preformed rings set in grooves around each specimen tube. A small segment of the braze ring in the nickel tubes is irradiated with an Ag-110 isotope for postflight evaluation of the metal flow patterns. Each specimen tube assembly is installed into a cylinder that contains an exothermic (heat producing) material. An electrical igniter is placed in one end of the cylinder and ignites a chemical mixture which in turn heats the exothermic mixture to its ignition point. Substantially all of the reaction products are solid, and no external oxygen supply is required for the reaction.

The crewman handles only the assembled container (fig. 12-36) and the internal operations are not visible to him. It is necessary only for him to install the package in the work chamber, initiate evacuation, and ignite the sample. The ignition of each sample is initiated by actuation of the trigger switch on the control panel. Approximately 90 seconds is required for the complete reaction, and about 2 hours 45 minutes is required for the experiment sample to cool. Each sample ignition and cooldown is a separate performance. After package installation and initiation of the first performance, the crewman returns to the facility only at predetermined times to initiate the remaining samples.

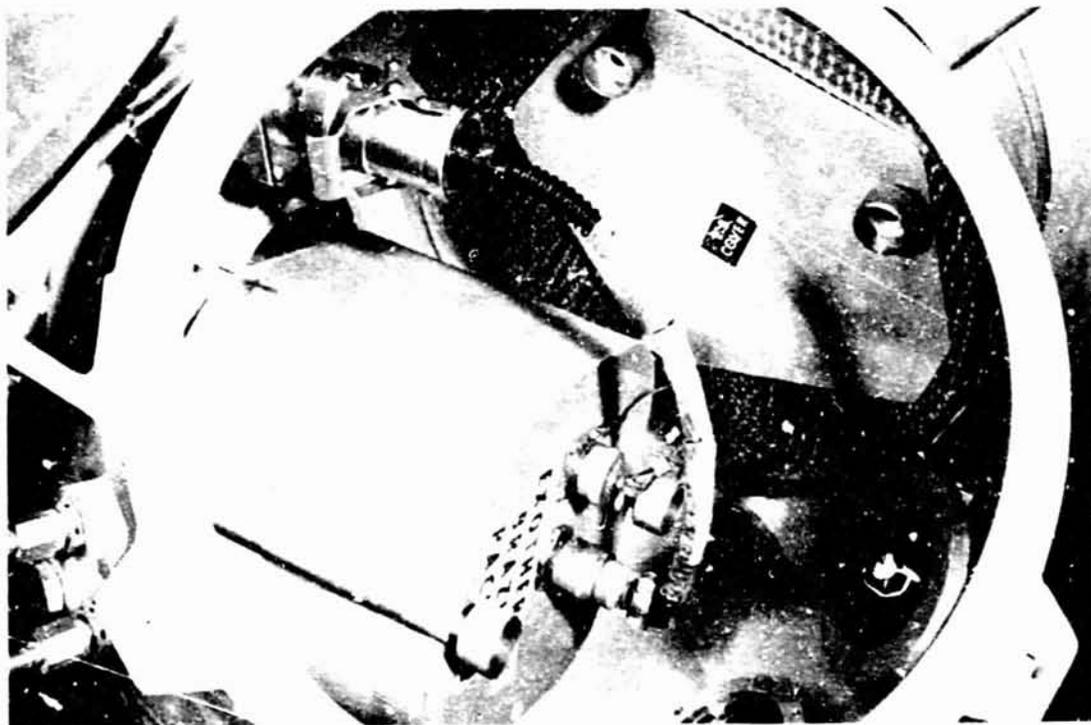


Figure 12-36.- Exothermic brazing experiment processing chamber installed in work chamber.

One of the samples was completed on Day 33 and the remaining three on Day 34. All hardware performed as expected. All four of the samples were returned to Earth along with comments from the crewmen performing the experiments. Figure 12-37 is a photograph of one of the returned samples.

Sphere Forming (M553).- The sphere forming experiment demonstrates the effects of zero gravity and space vacuum on the following processes: subcooling

of pure nickel prior to solidification, which is not possible to achieve on Earth; solidification of a nickel-tin alloy having a wide freezing range; solidification of a nickel-silver alloy having a narrow melting range which "cores" on solidification; and solidification of a nickel-copper alloy having a wide melting range but essentially no difference in density between the two elements.

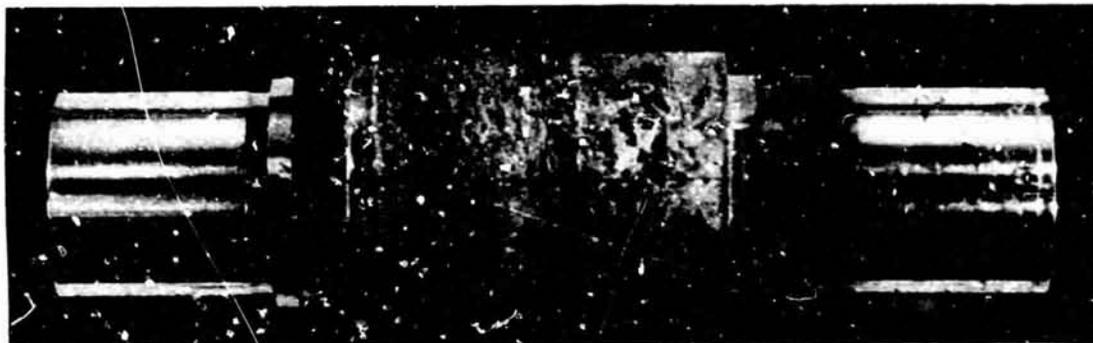


Figure 12-37. - Exothermic brazing experiment returned sample.

The samples are processed using the electron beam for the melting heat source. They are arranged on a wheel which rotates the samples through the path of the beam. Two separate wheels are used. Each wheel is of a pinwheel design with 15 "spokes" or positions for samples. The first position contains a tungsten target used for aligning the electron beam gun. The next three positions contain small cylindrical samples attached to the wheel by metal rods. These samples remain mounted after resolidification until they are cut from the wheel. The remaining 11 positions contain samples, each mounted to a ceramic post by a small metal rod called a "sting". The sting is retracted from the molten sample by a spring, allowing the sample to resolidify in a free floating state. Also, the sting retraction automatically removes power from the electron beam gun. The experiment operation involves mounting a specimen wheel to the indexing motor and then mounting this assembly in the work chamber (fig. 12-38). The motor indexes each sample on the specimen wheel through the electron beam. The melting and resolidification is observed by the crewman and photographed by a 16-millimeter camera. The 11 floating samples are collected in a container using the vacuum cleaner.

Processing of samples on the first specimen wheel was begun on Day 31. The crewman reported difficulty in aligning the electron beam on the target, and the pressure level in the chamber degraded while the electron beam gun was operating. On the fourth sample, the gun automatically turned off after 1 second of the normal 5-second melt time. When the pressure level approached  $1 \times 10^{-4}$  torr, the gun was turned off and the experiment delayed until the pressure decreased to  $1 \times 10^{-5}$  torr. On Day 32, the first specimen wheel was completed and the second started. The crewman reported that some samples on the first wheel had not completely melted when the gun turned off.

The crewman reported on Day 33 that he was having problems with the operation of the experiment. At times the electron beam gun could not be turned off except by opening the battery main circuit breaker. In addition, there was occasionally a blue glow in the work chamber. After consultation, it was decided to terminate operation of the experiment after the next normal turnoff of the electron beam gun. Seven of the 14 samples were completed before experiment termination.

- A. M553 electrical cable to M512 facility    C. M512 work chamber  
 B. M553 motor    D. M553 work sample

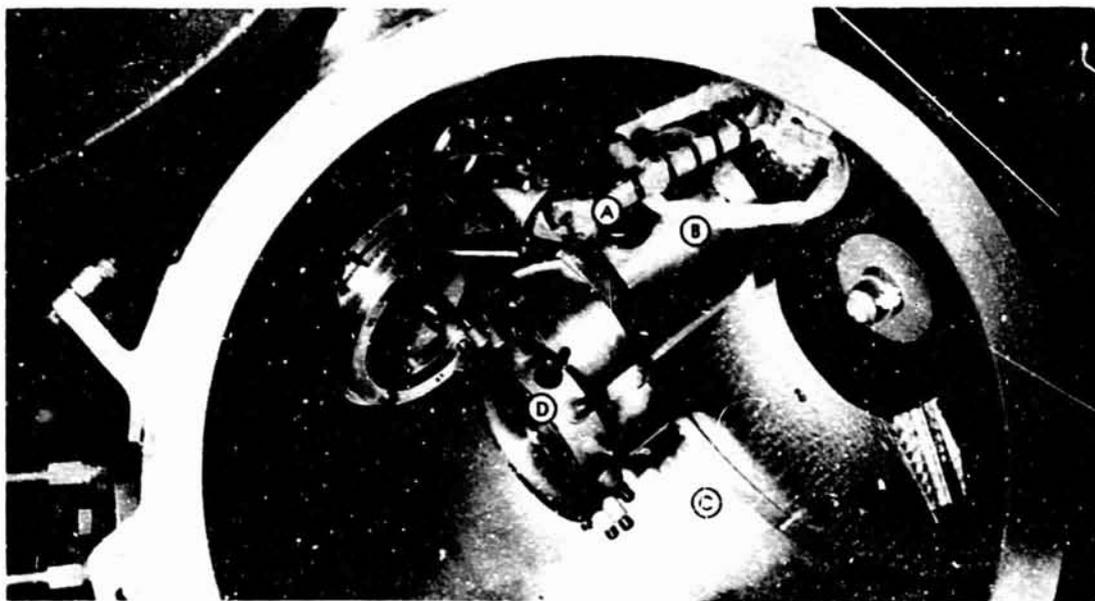


Figure 12-38.- Sphere forming experiment installed in work chamber.

The decision to terminate the experiment early was based on the limited time remaining to perform the exothermic brazing experiment, and the increased crew time being required to perform the sphere forming experiment. Outgassing of the samples during the electron beam gun operation caused the pressure in the chamber to increase. The increased pressure was causing a high voltage discharge in the chamber, which accounts for the blue glow the crewman witnessed. The cause of alignment problems on the first specimen is unknown. For some reason the 16-millimeter film coverage for that specimen did not start until the third sample. The film for the second specimen shows an excellent alignment of the gun and the target. The gun turned off after 1 second on the fourth sample of specimen wheel 1 because the electron beam struck the ceramic post and probably melted the sting. The films taken during that operation verify that the beam struck the post, and melting the sting will turn the gun off. Although the crewman reported that some of the samples on specimen wheel 1 did not melt completely before the gun turned off, preliminary analysis indicates that all samples on that wheel were sufficiently melted for complete scientific evaluation.

All samples on specimen wheel 1 were sufficiently melted and all 14 samples and the wheel were returned for evaluation. Seven of the 14 samples on specimen wheel 2 were successfully melted, and these samples, plus specimen wheel 2 with its remaining samples, were returned for evaluation. Approximately 200 feet of 16-millimeter type S0168 color film of the experiment operations was also returned along with the crew observations recorded during the performance. Figure 12-39 is a photograph of the returned specimen wheel 2.

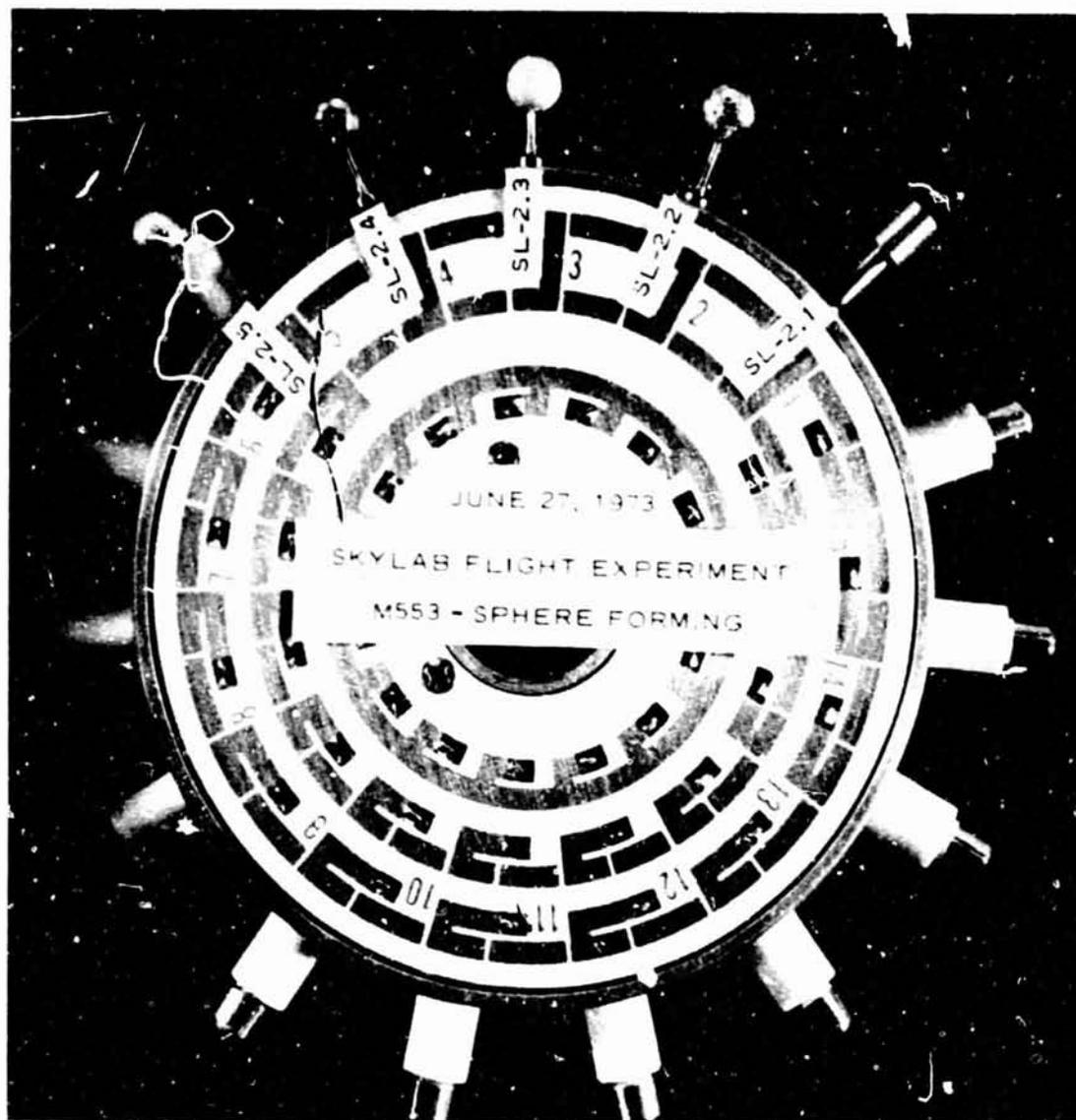


Figure 12-39.- Sphere forming experiment returned sample.

### 12.3.2 Multipurpose Electric Furnace (M518)

Experiment M518 is a multipurpose electric furnace system in which experiments on solidification, crystal growth, and other processes that involve material phase changes can be performed. The system consists of three main parts: the furnace, designed to interface with the M512 materials processing facility; a programmable electronic temperature controller which controls the temperature levels in the furnace; and experiment cartridges which contain the sample materials. The furnace has three specimen cavities so that three material samples can be processed at a time. The furnace is constructed to provide three different temperature zones along the length of each sample cavity, as follows:

- a. A constant-temperature hot zone at the end of the sample cavity where temperatures up to 1000°C can be reached.
- b. A gradient zone next to the hot zone where temperature gradients ranging from 20 to 200°C per centimeter can be established in the samples.

c. A cool zone in which heat conducted along the samples is rejected by radiation to a conducting path that carries the heat out of the system.

Each sample of material is enclosed in a cartridge that further controls the actual temperature distribution applied to the sample. Eleven different processes are performed in the furnace. Each process has three sample cartridges, which are processed at the same time. The temperature controller provides active control of the furnace temperature. The crewman sets it at the temperature specified for processing the samples. Two timing circuits in the controller enable the crewman to program the soak time spent at the set temperature and the cooling rate of the furnace at the end of the soak period. Active temperature control continues during programmed cooling. Once the cartridges are installed in the furnace and the system is activated by the crewman, the system operates automatically except when the complete system is shut down. The material cartridges are returned to Earth for examination. The furnace, temperature controller, and sample cartridges are shown in figures 12-33 and 12-40.

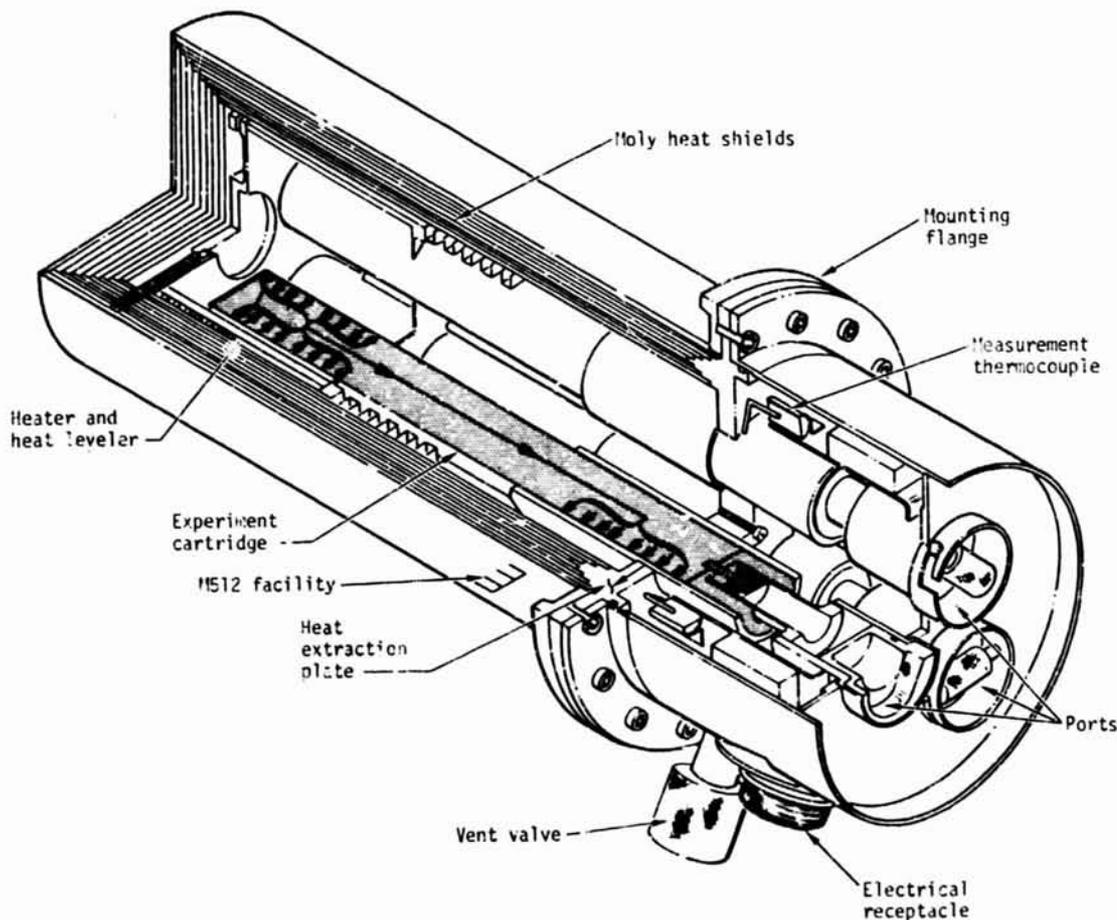


Figure 12-40.- Multipurpose electric furnace.

The furnace has its own electrical and instrumentation and communications interfaces with the docking adapter. The electrical interface provides 28 +2, -4 vdc for heating control. The instrumentation and communications interface processes the two furnace temperature measurements. The temperature measurements are telemetered to Earth in real time or recorded for subsequent transmission.

The furnace was operated during the second and third manned periods. Eleven processes (33 cartridges) were performed during the second period and 7 processes (21 cartridges) during the third. The furnace facility was first set up on Day 118. The setup of the facility required transferring the experiment samples from their stowage location in the workshop, installing the furnace in the facility, preparing the facility for the experiments using it, and installing the temperature control panel. A thin film of thermal grease was applied between the furnace and the heat sink where it was installed inside the materials processing in space facility. Figure 12-41 shows the furnace installed in the facility.

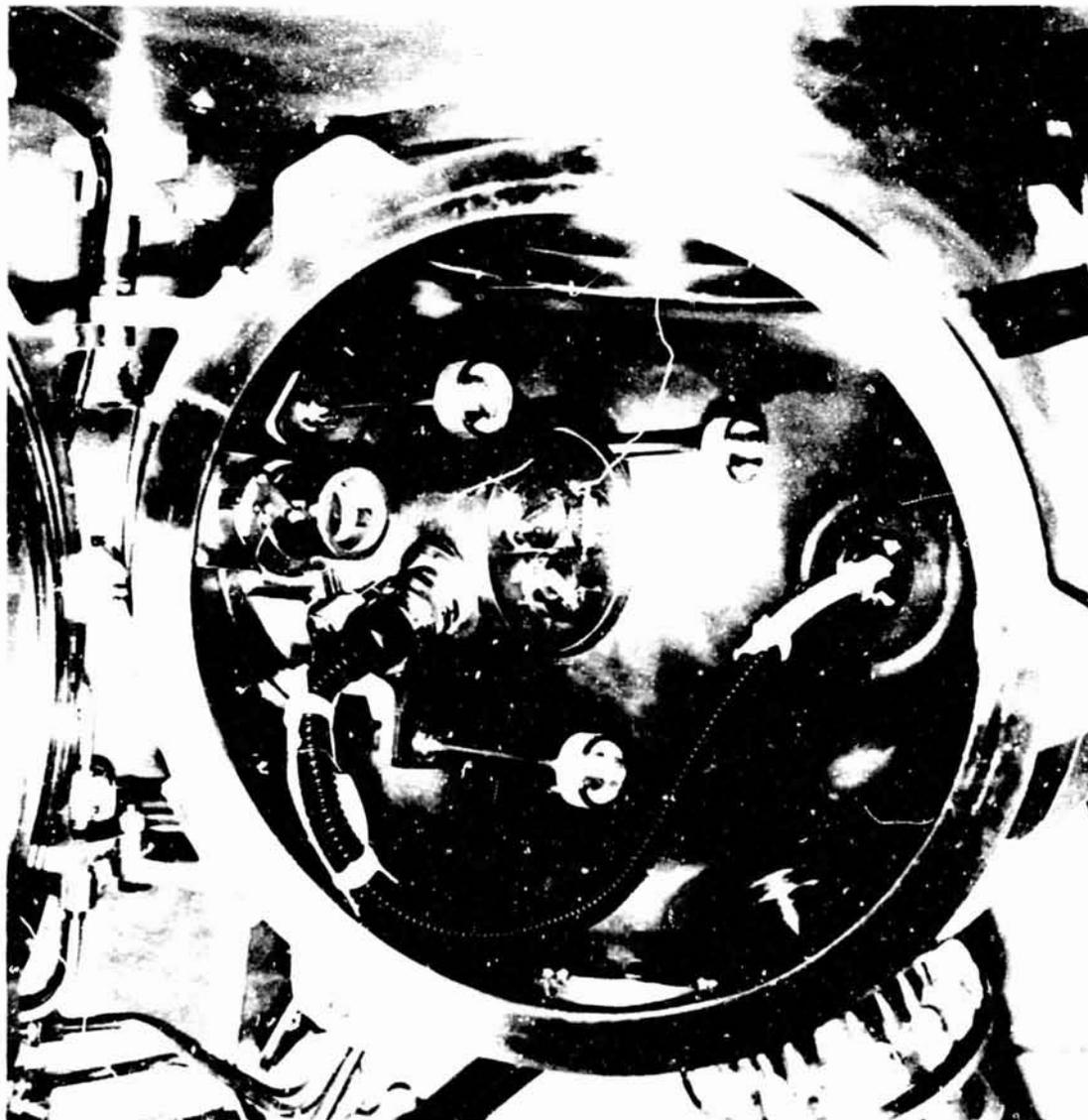


Figure 12-41.- Multipurpose electric furnace mounted in work chamber.

When the furnace facility was set up and ready to operate, the three sample cartridges were inserted in the furnace ports and a vacuum was initiated. The crewman then turned on the electric power, performed a test of all indicator lights, and set the experiment soak temperature, soak period, cooldown rate, and proper heaters on the control panel. When the proper pressure had been obtained in the facility work chamber ( $5 \times 10^{-4}$  torr maximum), the experiment was switched

on at the control panel. The control panel caused the electric furnace to heat to the preset temperature and maintain this soak temperature for the preset amount of time. The control panel then caused the furnace to cool down at the rate which was predetermined for the experiment operation. The experiment was completely automatic from the time it was initiated with the start switch through cooldown.

Table 12-III.- Multipurpose Electric Furnace Operations

Experiment	Day commenced	Day concluded
M557	118 and 222	119 and 224
M562	120 and 237	121 and 238
M566	121 and 236	122 and 237
M564	122	123
M559	123	125
M563	125 and 231	126 and 232
M561	126 and 229	127 and 230
M560	127 and 227	128 and 228
M565	128	129
M558	129	130
M556	130 and 238	132 and 240

When the furnace had cooled down, the work chamber was repressurized and the completed samples were removed. A new set of samples was installed and the procedure repeated. Table 12-III is a listing of when each experiment was performed. Table 12-IV lists the performance parameters of soak temperature, soak time, and cooldown rate for each process performed. The following experiments were performed in the multipurpose electric furnace.

Vapor Growth of IV-VI Compounds

(M556).- This experiment determines the degree of improvement that can be obtained

in the perfection and chemical homogeneity of crystals grown by chemical vapor transport under weightless conditions. Mixed crystals of compound semiconductor germanium selenide and germanium telluride were grown by chemical transport through a temperature gradient in a transport agent, iodine vapor, from polycrystalline sources of the two component materials. The growth process was carried out in sealed quartz ampoules contained in the sample cartridges.

Table 12-IV.- Experiment Performance Parameters

Experiment number	Manned period	Soak temperature, °C	Soak time, hours	Cooldown rate, °C/min
M556	Second	581	33.2	Passive
M556	Third	460	33.1	Passive
M557	Second	724	4.1	Passive
M557	Third	726	4.0	Passive
M558	Second	796	0.9	Passive
M559	Second	1012	2.3	0.6
M560	Second	657	1.0	0.6
M560	Third	650	1.1	0.6
M561	Second	1007	3.7	Passive
M561	Third	991	1.0	0.6
M562	Second	792	0.9	1.2
M562	Third	803, 655	1.1	1.2, Passive
M563	Second	976	16.3	0.6
M563	Third	1011	16.3	0.6
M564	Second	926	1.0	0.6
M565	Second	1036	1.0	Passive
M566	Second	849	1.0	2.4
M566	Third	865	1.1	2.4

Immiscible Alloy Compositions (M557).- This experiment determines the effects of near-zero gravity on the processing of material compositions which normally

segregate on Earth. The experiment used three ampoules which contained sample materials as follows:

- a. Ampoule A - Isothermal solidification of a 45-45-10 percent by weight lead-zinc-antimony ternary couple which exhibits both liquid and solid state immiscibility.
- b. Ampoule B - Isothermal solidification of a 76.8-23.2 percent by weight gold-germanium binary couple which exhibits essentially complete immiscibility in the solid state.
- c. Ampoule C - Directional solidification of a 70-15-15 percent by weight lead-indium-tin ternary couple which exhibits limited solubility in the solid state.

Each of the three ampoules was individually packaged, ampoules A and B in stainless steel and ampoule C in quartz tubing. Each cartridge contained one of each type of ampoule.

Radioactive Tracer Diffusion (M558).- This experiment measures self-diffusion and impurity diffusion effects in liquid metals in space flight and characterizes the disturbing effects, if any, caused by spacecraft acceleration. Three rods of zinc metal were prepared with a section of radioactive zinc ( $Zn-65$ ) plated to one end of each of two rods and in the midsection of the third rod. The zinc rods, which were encased in tantalum and sealed in cartridges, were melted and held at a constant temperature while the radioactive atoms diffused into the liquid metals, and were then allowed to solidify.

Microsegregation in Germanium (M559).- This experiment determines the degree of microsegregation of doping impurities in germanium caused by convectionless directional solidification under conditions of weightlessness. It further determines if the low-gravity environment materially influences the homogeneity of the impurity distribution. Single-crystal rods of germanium doped with antimony (an electron donor, N-type), gallium, and boron (electron acceptors, P-type) were placed in cartridges and positioned so that one end of each rod extended into the furnace hot zone. When the furnace was heated, only the part of each rod that was within the hot zone was melted, leaving a solid part to serve as a seed for regrowth of the crystal when the melt resolidified. The rods were directionally solidified at the slowest available cooling rate to promote formation of single crystals.

Growth of Spherical Crystals (M560).- This experiment grows doped indium antimonide crystals of high chemical homogeneity and structural perfection for a study of their resulting physical properties in comparison with theoretical values for ideal crystals. Prepared samples of indium-antimonide, encased in cartridges, were melted to produce suspended drops of molten material attached to solid seed crystals. The drops were solidified by removing heat through the seed crystals while heat losses from the surfaces of the liquid drops were compensated. The crystalline material in contact with the seed grew inside the drop and the liquid on the drop surface was the last to solidify. This eliminated mechanical strain caused by a volume change from freezing.

Whisker-Reinforced Composites (M561).- This experiment produces void-free samples of silver, reinforced with oriented silicon carbide whiskers. Sintered rods of silver containing distributions of unidirectionally-oriented silicon carbide whiskers (1 micron diameter by 1 millimeter long) were melted in the

furnace. Pressure from a piston, actuated by a spring, was used to force voids from the melt and to promote wetting of the whiskers by the matrix material.

Indium Antimonide Crystals (M562).- This experiment produces doped semiconductor crystals of high chemical homogeneity and structural perfection for evaluation of the influence of weightlessness in obtaining these properties. High quality single crystals of indium antimonide were prepared in the laboratory, doped with tellurium, precision machined and etched to fit into heavy-wall quartz ampoules, and sealed. The ampoules were then enclosed in the metal cartridges. Half of each crystal (about 3 inches in length) was melted in the furnace and regrown at a rate of 0.5 in./hr using the unmelted half as a seed. Two procedures were added for the repeat performance during the third manned period. First, the work chamber was physically hit approximately 2 hours after the start of controlled cooldown. This provided a known time disturbance during the resolidification process to assist in the ground analysis of the crystals. Approximately 1 hour later, the temperature controller was reconfigured to provide a second soak period (at approximately 650°C) for 1 hour and then the cooldown reinitiated.

Mixed III-V Crystal Growth (M563).- This experiment determines how weightlessness affects directional solidification of binary semiconductor alloys. If single crystals are obtained, it will determine how their semiconducting properties depend on alloy composition. Alloys of indium antimonide and gallium antimonide in varying proportions were placed in separate fused silica ampoules. The ampoules were encased in the cartridges, melted in the furnace, and directionally solidified at the slowest available rate.

Halide Eutectics (M564).- This experiment produces controlled structures in samples of fiberlike sodium fluoride-sodium chloride eutectic, and measures their physical properties. Three ingots of the eutectic, approximately 0.5 inch in diameter and 4 inches long, were grown by melting the alloys and then cooling them directionally at the slowest available rate.

Silver Grids Melted in Space (M565).- This experiment determines how pore sizes and pore shapes change in porous structures when they are melted and resolidified in space. The samples consisted of three ampoules. Ampoule A contained eight silver disks, 14 millimeters in diameter and 0.4 millimeter thick. Each disk had one or more holes of various shapes and sizes. Ampoule B was the same as ampoule A except that the thickness of the disks was 0.5 millimeter. Ampoule C contained a single sample of silver fibers 0.4 millimeter in diameter and 10 to 15 millimeters long. The fibers were compressed and annealed to form a prism 40 by 14 by 4 millimeters with a porosity of 30 percent. Each ampoule was then encased in a cartridge for sample melting in the furnace and resolidification.

Aluminum-Copper Eutectic (M566).- This experiment determines the effects of weightlessness on the solidification of lamellar structure in a eutectic alloy when directionally solidified. Three aluminum-copper alloy rods 0.25 inch in diameter were used. One rod was installed in each furnace cartridge, partially melted, and directionally solidified. During the third manned period performance, approximately the first hour of controlled cooldown was accomplished while Skylab was in the Z local vertical attitude. This was done to determine if differences exist in resolidification patterns between the Z local vertical and solar inertial attitudes. In the first, the sample remains at the same altitude all around the Earth, whereas in the second, there is a small cyclical variation in the altitude of the sample.

The multipurpose electric furnace hardware performed well and no malfunctions were encountered. There was a problem however, in the potentiometer that controls the soak temperature. It was discovered when the first three samples were processed that the actual temperature was 10 to 15°C lower than it should have been. A correction factor for the potentiometer used for the remainder of the samples brought the temperature more in line with expectations. It was discovered that the furnace is very sensitive to variations in the workshop voltage levels. During the second manned periods the voltage averaged 28.6 to 28.7 vdc and some heat-up times were as much as an hour less than expected. During the third manned period, the voltage averaged 28.4 to 28.6 vdc and the heat-up times were somewhat longer. All systems supporting the experiment furnace functioned as expected.

All samples processed in the furnace were returned to Earth. Preliminary analysis indicates that results obtained from some of the processes are far superior to the results that can be obtained on Earth.

### 12.3.3 Zero Gravity Flammability (M479)

The zero gravity flammability experiment (M479) was the igniting of various materials in the atmosphere to observe the extent of surface propagation flash-over to adjacent materials; the rates of surface and bulk flame propagation under zero convection; and the extinguishment by vacuum, water spray, and self-extinguishment.

Six different substances were used for sample materials: aluminized Mylar film, polyurethane foam, nylon sheet, neoprene-coated nylon fabric, bleached cellulose paper, and Teflon fabric. Thirty-seven separate samples were used. Each sample was supported by a metallic frame and ignited by an electrically heated filament. A flammability specimen holder was the mechanical and electrical interface between the flammability sample and the zero-gravity connector in the work chamber. Figure 12-42 shows the sample holder with a sample installed. The holder positioned the specimen in the approximate center of the chamber, in view of the 16-millimeter data acquisition camera. Figure 12-43 shows sample 7 prepared for stowage in the workshop.

In a typical sample operation the sample was installed on the sample holder, and this assembly was then installed onto the zero-gravity connector in the work chamber. The sample identification number was recorded on film by activation of the sample identification switch on the control panel. Ignition of the sample occurred when the data start switch was activated, and the camera automatically ran for a time period preset on the control panel.

The sample was extinguished by one of three methods: self-extinguishment, or the sample burning out by itself; vacuum quench, or opening of the vent line to space vacuum; or water quench, with 2 ounces of water sprayed on the sample.

Samples 1 through 12 consisted of two samples of each material that were extinguished using the self-extinguishment method. Samples 13 through 18 consisted of one sample of each material that tested the vacuum method of extinguishment. Samples 19 through 24 tested the water quench method. Samples 25 through 30 were partially supported on the frame and the paths and rates of float were observed as the specimens burned away. Samples 31 through 37 tested flash-over between two strips of material that were separated by gaps of various dimensions.

- A. Sample and igniter
- B. Sample holder
- C. Push-pull connector

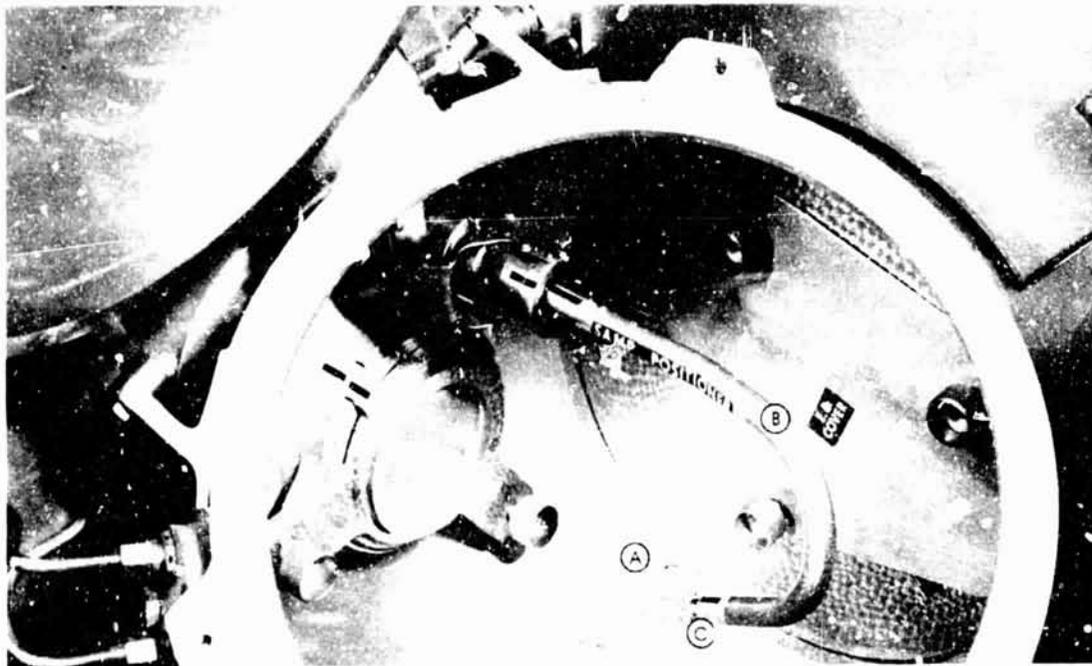


Figure 12-42.- Typical sample for the zero gravity flammability experiment installed in the work chamber.

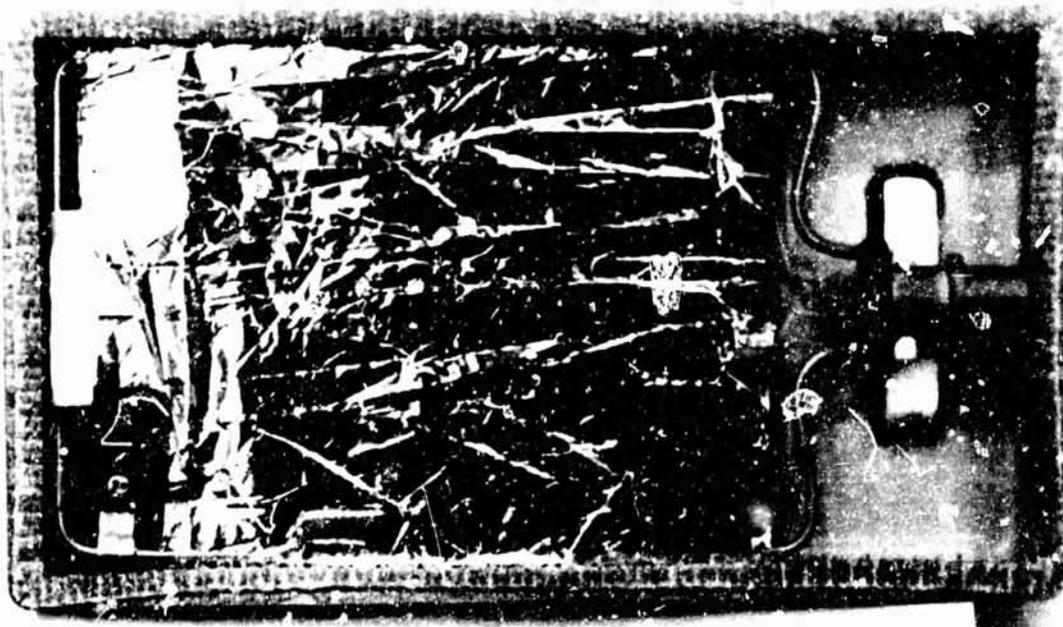


Figure 12-43.- Zero gravity flammability experiment sample 7 stowed configuration.

The experiment was performed using samples 1 through 18 on Day 267, 19 through 30 on Day 268, and 31 through 37 on Day 270. The experiment equipment worked normally; however, the materials processing in space facility water quench system did not function as expected. By using the hand pump on the facility accumulator, the crewman was able to provide sufficient water to obtain water quench data on at least two of the samples. There was not time to perform a malfunction isolation of the water problem. It was subsequently concluded that the water source tank in the workshop was not pressurized sufficiently. There were no procedural requirements for the crewman performing the experiment to pressurize or verify pressure in the tank. The remaining interfacing and supporting systems functioned properly.

Four rolls of 16-millimeter film data and the remains of four samples were returned for analysis. In addition, crew comments on the experiment performance and television coverage of three samples were recorded and returned.

#### 11.4 ENGINEERING AND TECHNOLOGY

The engineering and technology experiments were selected to provide data necessary for the development of future manned space stations. The results provide a better understanding of how man performs in space, what tools he needs to accomplish his tasks, and what his influence is on the space environment. Quantitative information from some of the experiments on the space environment's effects on materials and functions also supported the analyses of the Skylab systems and other experiments.

This group of experiments can be classified into three general categories: zero gravity studies, thermal control coatings, and contamination. The zero gravity studies include the habitability of crew quarters, manual navigation sightings, crew vehicle disturbances, and foot-controlled maneuvering unit experiments. They are particularly oriented toward the interaction of man with a zero gravity environment. Their scope ranges from the crewmen's preferences in the arrangements of habitable areas to testing their proficiency in making space navigation measurements after being weightless for an extended period. They also include the measuring of forces that man exerts on the spacecraft while he moves around inside and the testing of an astronaut maneuvering unit. The two thermal control coatings experiments require very little participation by the crewman. The first begins collecting data 36 hours prior to launch through several minutes of Earth orbit and requires no crew participation. The other one starts when the payload shroud is jettisoned; different samples are retrieved at three different times during the mission during extravehicular activity. The inflight aerosol analysis and contamination measurements experiments are devoted to obtaining data on contamination type particles. One is concerned with collecting aerosol particles within the habitable area of the laboratory and returning them to Earth. These particles are of interest because they relate to the crewmen's well-being. The other measures the magnitude of the contamination within the induced atmosphere surrounding Skylab. Outside contamination is of interest because it can cause degradation of optical surfaces and solar energy converters.

One experiment, the proton spectrometer is mounted outside the laboratory and does not fall in either of the categories listed. The proton spectrometer maps the high radiation areas that Skylab passes through. The instrument's operation is automatic and requires no crew participation.

## 12.4.1 Thermal Control Coatings (D024)

The thermal control coatings experiment (D024) evaluates the effects of near-Earth space environments on selected experimental thermal control coatings and polymeric filmstrips, and provides calibration values for ground simulation of the space environment. The experiment hardware (fig. 12-44) consists of 2 panels, each containing 36 thermal control coating samples. The samples are 2.54-centimeter diameter disks coated with various selected thermal control coatings. In addition, there are 2 panels that each contain 32 strip samples of polymeric film. The polymeric strips are 7.62 centimeters long; 8 of the

- A. Thermal control coating
- B. Polymeric strips
- C. Return containers

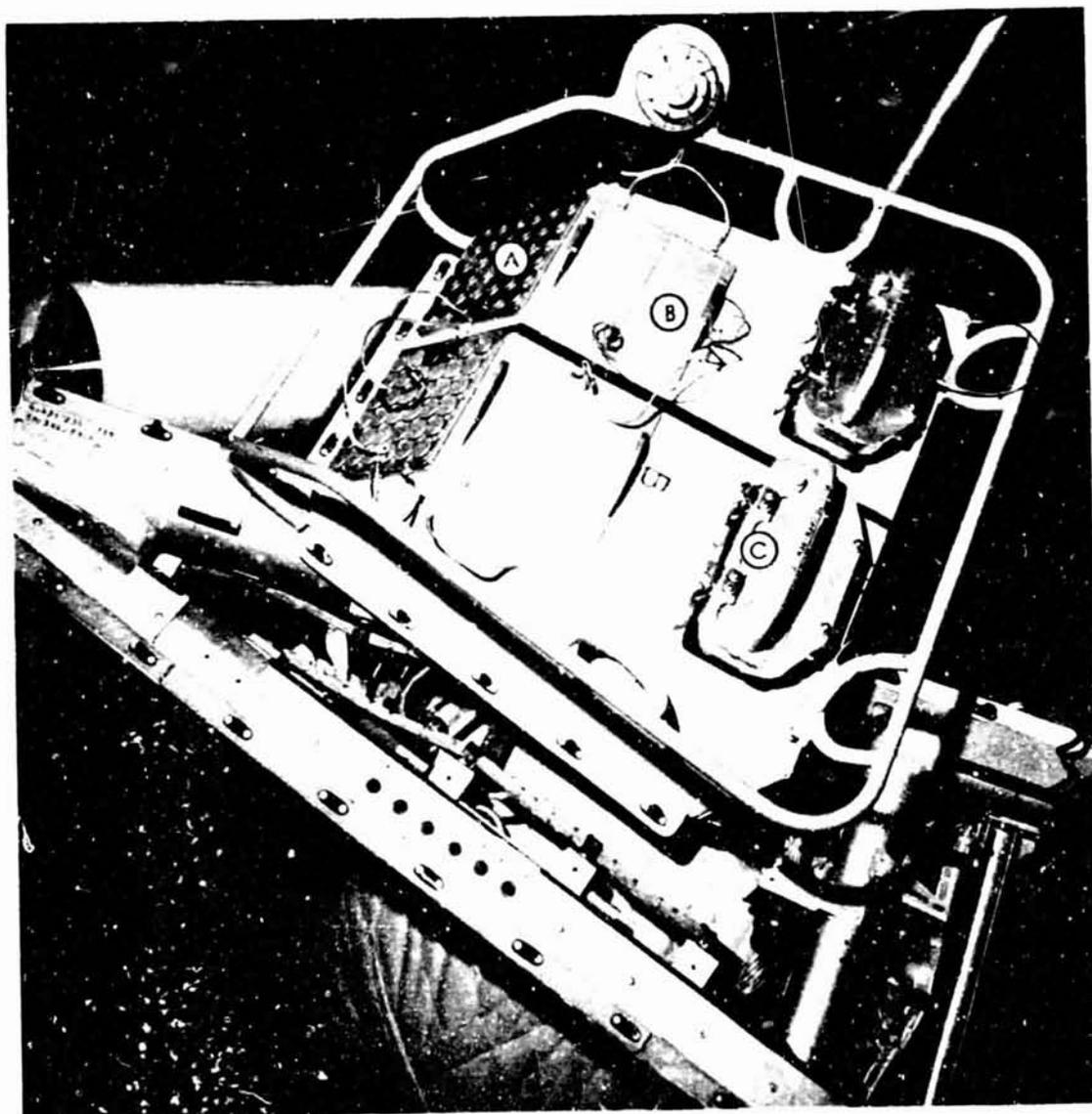


Figure 12-44.- Thermal control coatings experiment in operational location.

strips are 1.27 centimeters wide and 24 strips are 0.64 centimeter wide. All panels are square plates, about 17 centimeters on a side and 0.6 centimeter thick. Each has a flexible handle to prevent contamination of the samples while handling. The panels are attached with snap fasteners and pip pins to the airlock truss assembly outside the workshop. They are protected by the shroud during launch, and are not affected by the launch environment. Two containers are provided for return of the samples. The containers are stowed adjacent to the panels, thereby allowing the panels to be sealed in the containers in the space vacuum. The hermetically sealed container maintains a vacuum for the samples until they reach the laboratory, where they are placed in a vacuum chamber. Tests are performed on the returned samples and the results are compared with the results obtained from the ground control group samples.

The samples were exposed to the space environment when the shroud was jettisoned from the Saturn Workshop. They were retrieved by the crewman during extravehicular activities on Days 37 and 132. These samples were returned to Earth in the command module and delivered to the scientists within 4 days of splashdown from each manned period. Because of contamination found on these samples, one new panel of each sample and a return container were launched and deployed during the third manned period. The new panels were deployed during extravehicular activities on Day 193 and retrieved on Day 266. These samples were therefore not exposed to control rocket exhausts during docking, undocking, and flyaround maneuvers by the command and service module. When the container with the new samples was returned to the scientists it was found that atmospheric pressure existed inside the container, not space vacuum as intended.

The hardware functioned properly under normal conditions. However, the crewman experienced difficulty in deploying the resupplied sample panels. The hardware design had not provided for installation in orbit by a suited crewman; nevertheless, installation was successful. The crewman failed to close the lid on the return container after stowing it adjacent to the newly deployed panels, and the open lid allowed solar radiation to impinge on the container seals for 73 days. When the container was returned to the laboratory, it had not maintained the space vacuum as intended. The crewman reported that some of the thermal control sample disks from the second manned period appeared to be coming debonded. This condition was not evident when the samples were returned to the scientists back on Earth.

One thermal control sample panel and one polymeric film strip panel inside the return container were returned from each manned period. All returned hardware showed evidence of a yellowish-brown contamination that apparently related to exposure time and sunlight. Effects of this contamination obscured the degradation of the samples expected because of solar radiation. It also obscured any atmospheric recombination which could have affected the last samples because of the loss of vacuum on return. The source of this contamination is now under investigation.

#### 12.4.2 Thermal Control Coatings, Instrument Unit (M415)

The thermal control coatings experiment (M415) that is launched on the instrument unit determines the degradation effects of prelaunch, launch, and space environments on the thermal absorption and emission characteristics of various coatings commonly used for passive thermal control. The hardware consists of two identical panels as shown in figure 12-45. The coating samples are thermally isolated from surrounding structures, and each row is protected by a removable

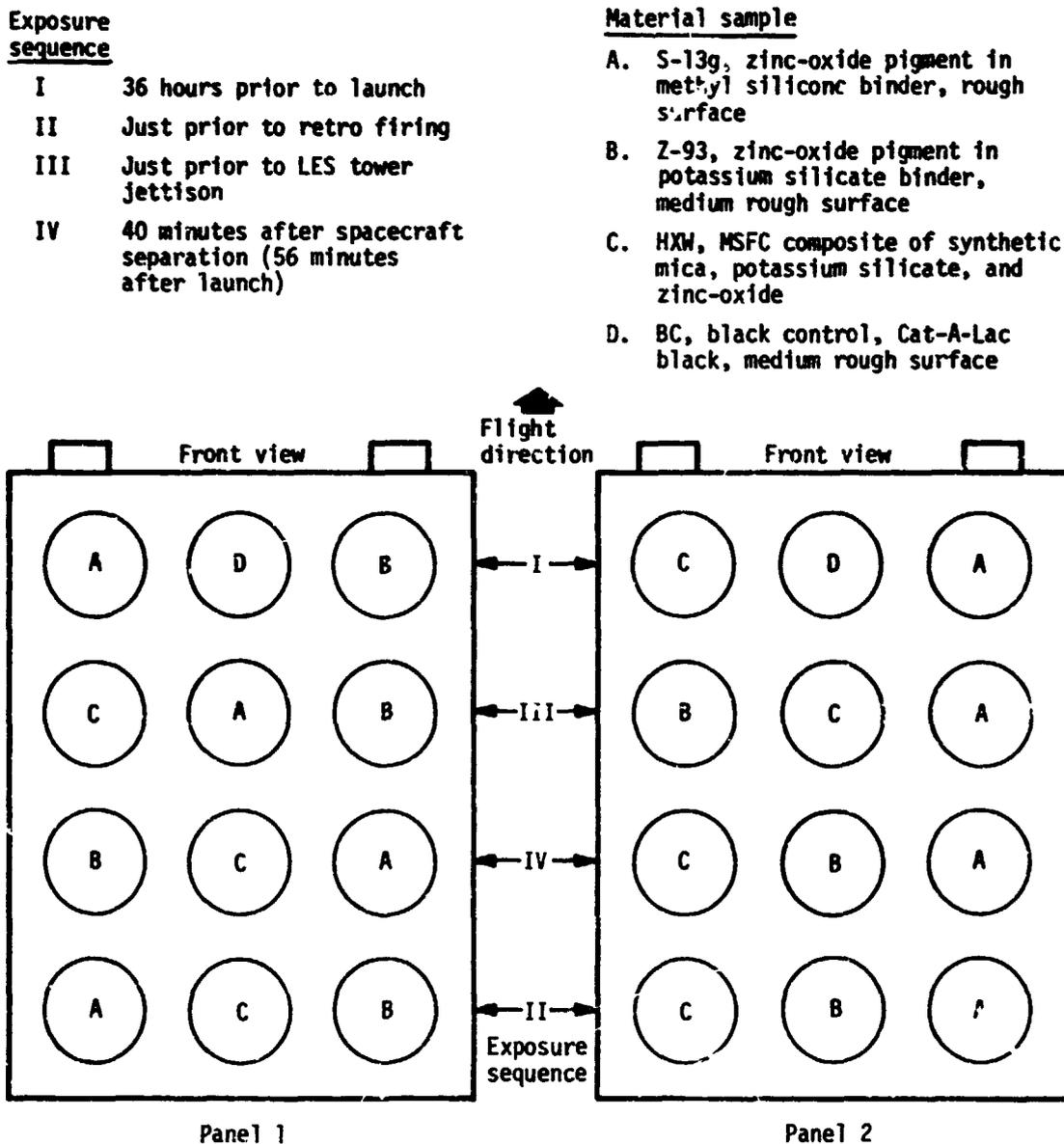


Figure 12-45.- Instrument unit thermal control coatings experiment specimen panels.

cover. The panels are mounted 51 degrees apart on the instrument unit of a Saturn IB launch vehicle. This location allows a retrorocket to impinge on one panel. The instrument unit provides attitude control of the stage and of the experiment. It maintains the X axis along the flight vector perpendicular to the local vertical and rolls so that at local noon the sunline passes midway between the two sensor panels, illuminating them equally. This experiment does not permit detailed spectral reflection measurements; the thermal properties are measured by temperature sensors. The data are telemetered to the ground when the spent stage is in contact with selected ground stations. Telemetry data begin at launch and are required for 5.75 hours. The experiment was flown on the vehicle that carried the first crew into Earth orbit. It performed satisfactorily and as predicted. The six protective covers remaining after launch

were deployed at the scheduled times in accordance with the flight plan. This was confirmed by telemetry records of the cover release event signals and the corresponding step change in the relevant specimen temperatures. All temperature sensors worked properly and usable data were obtained from each of them. The instrument unit interfaces supported the experiment in a normal manner, and the attitude control system positioned the spent stage so the panels were properly aligned with the Sun.

Returned data consisted entirely of telemetry. The experiment data included event signals and temperature measurements. Event signals verified the deployment of the covers. These properly coincided with the programmed event sequence. Temperatures of the 12 specimens in each panel (and the panels themselves) were monitored over selected ground stations at the rate of 12 samples per second. Equilibrium temperatures were reached on the daylight portion of two orbits. This condition provided all the necessary information for calculating the absorptivity/emissivity ratio for all specimens, from which their surface conditions could then be determined.

#### 12.4.3 Habitability of Crew Quarters (M487)

The habitability of crew quarters experiment (M487) evaluates the features that make Skylab livable. Habitability features such as architecture, environmental elements, and communications techniques affect everyday spacecraft activities and crew performances. Such items as food, water, garments, and personal hygiene facilities are minimum requirements for living in space. Throughout the manned periods of Skylab, the crewmen were asked to evaluate their performances of activities and the adequacy of their habitation. To aid the crewmen in their evaluation, the following portable measuring instruments are provided:

- a. Velometer - Measures velocity of air movement in the workshop.
- b. Measuring tape - Measures distances to evaluate pertinent sizes and locations.
- c. Sound level meter - Measures sound pressure levels in the workshop.
- d. Frequency analyzer - Analyzes the sound spectrum in the workshop.
- e. Ambient thermometers - Measures ambient air temperatures in the workshop.
- f. Digital thermometers - Measures temperatures of walls, solids, and surfaces in the workshop.
- g. Force gage - Measures forces required to open or close lockers, drawers, and panels.

The crewmen's tasks and activities associated with the habitability evaluation were arranged and categorized into functional objectives. These items were scheduled into the daily flight plans at moments of opportunity and other times when activities to be photographed were being performed. The crew documented with photography and tape-recorded comments their evaluation of the habitability features of the Saturn Workshop. They also obtained film sequences of selected activities which demonstrated their adaptation to zero gravity. The crew completed 97 percent of the functional objectives during the first manned period and 100 percent in the last two periods. They reported no problems relative to the use of checklists and procedures. The portable measuring instruments functioned normally. In fact, the crew used the force gage to calibrate and evaluate the hardware of two other experiments. Tape-recorded comments of the crewmen's

evaluations were downlinked to Earth throughout the manned periods. The experiment photography was integrated throughout the 400-foot, 16-millimeter cassettes which were returned at the end of each manned period. The applicable scenes were retrieved by editing the film.

#### 12.4.4 Manual Navigation Sightings (T002)

The manual navigation sightings experiment (T002) investigates the effects of space flight environment (including long mission time) on a navigator's ability to take space navigation measurements using hand-held instruments. The equipment consists of two hand-held instruments, a sextant and a stadimeter (fig. 12-46 and 12-47). The sextant, similar to a marine sextant, is used to measure the angles between celestial bodies. The stadimeter is used to measure the distance (altitude) from the spacecraft to a planet (Earth). This is accomplished by viewing a horizon segment of the planet and measuring the apparent elevation angle between the arc and chord centers of the segment. The split optical display of the stadimeter allows the reference points on the segment to be optically aligned. The apparent angle between the points is read out on the instrument. By knowing the diameter of the planet, the distance from the spacecraft to the planet can be calculated. A collapsible hood to block out background light is an auxiliary component of the experiment.



Figure 12-46.- Sextant.

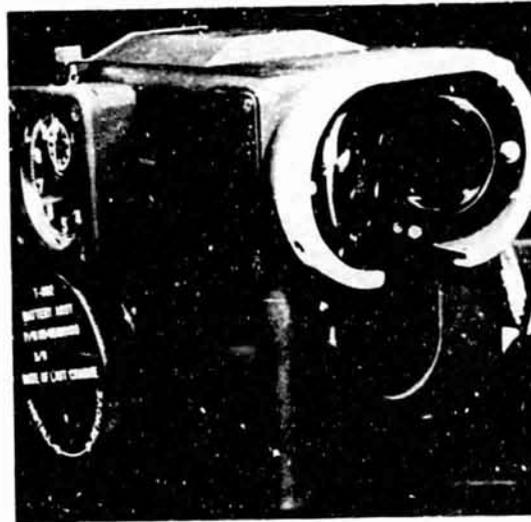


Figure 12-47.- Stadimeter.

Sightings made with the sextant and stadimeter are classified as midcourse and orbital navigation sightings. Sightings taken with the sextant provide data that are applicable to both midcourse and orbital navigation. Sightings taken with the stadimeter are applicable to orbital navigation. A sequence of angle measurements between different stars and the Earth's night and day horizon is included and referred to as a combined operational sighting. Midcourse sightings are used to determine the crewman's proficiency in extended periods of weightlessness. Orbital sightings are used to evaluate an orbital navigation system.

The experiment was scheduled for the second and third manned periods. It was planned to be performed 34 times each period at the convenience of the crew, and on a noninterfering basis with other experiments. It was actually performed 32 times during the second manned period and 25 times during the third manned

period. Sightings were taken through the wardroom window. The collapsible hood was arranged over the window to block out the internal lights. Sightings were taken by one crewman during each period.

The experiment was performed fewer times than planned because of limited crew time. Most sighting periods required 10 to 15 minutes, except for the operational sightings, which required an hour or more. High quality orbital navigation sightings could not be performed as planned because the Earth horizon was too diffuse to sight on. This characteristic and the length of time required for combined operational sightings caused the operational sightings to be cancelled for the third period. The last two sessions of midcourse sightings during the third period provided the best data from that period. Previous sightings during that period had violated the checklist statement which required removal of the transparent protective shield from the window. Voice recordings of the experiment data were made by the crewmen and transmitted to Earth.

Although the night Earth's horizon is too diffuse and nonuniform to use as a target for high quality orbital sightings, the data obtained indicated that a safe reentry could be made. Sightings taken through the wardroom window protective shield resulted in biases and deviations, thereby affirming the need for high quality optical windows. The window hood was reported to be effective and necessary in reducing reflected glare, but was somewhat awkward to handle. Both crews reported that the instrument adjustment knobs could be bumped or jarred, causing the measurement indication to shift. This could be minimized by redesign or new approaches. Also, both crews reported difficulty in locating a specific star in the field of view. A variable field of view could solve this difficulty. A variable field of view is an advantage because a wide field makes star identification easier and a narrow field improves precision.

While the voice recording technique for recording data measurements was accurate, operational applications could use direct wiring to a computer. One crewman suggested a digital time display in the field of view to be frozen at the instant of measurement. Also suggested was a modification to include the data display in the instrument's field of view to avoid readaptation of the operator's vision for subsequent sightings and readings.

All data from the experiment were contained in voice recordings. The recordings included data from 57 performances of the experiment. The data verify that man's proficiency in operating the instruments is maintained after 69 days in orbit.

#### 12.4.5 Inflight Aerosol Analysis (T003)

The inflight aerosol analysis experiment (T003) measures the aerosol particulate matter concentration and distribution in the habitable areas of Skylab during each manned period. The experiment detects, measures, and collects for return to Earth samples of the airborne particles within Skylab at certain times and locations. The instrument is a multichannel, battery-operated particle counter capable of sorting aerosol particles larger than 1 micron into size groups: 1 to 3, 3 to 9, and 9 to 100 microns (fig. 12-48). Each group is totaled and displayed on the instrument at 8-second intervals. The collection system allows the particles to be returned for postflight analysis, including analysis of shapes and compositions. Measurements are made at assigned locations within Skylab. Each location is assigned its separate section of the instrument filter. This permits collected particles to be traced to the location where they are collected. The filters have eight selectable sections.

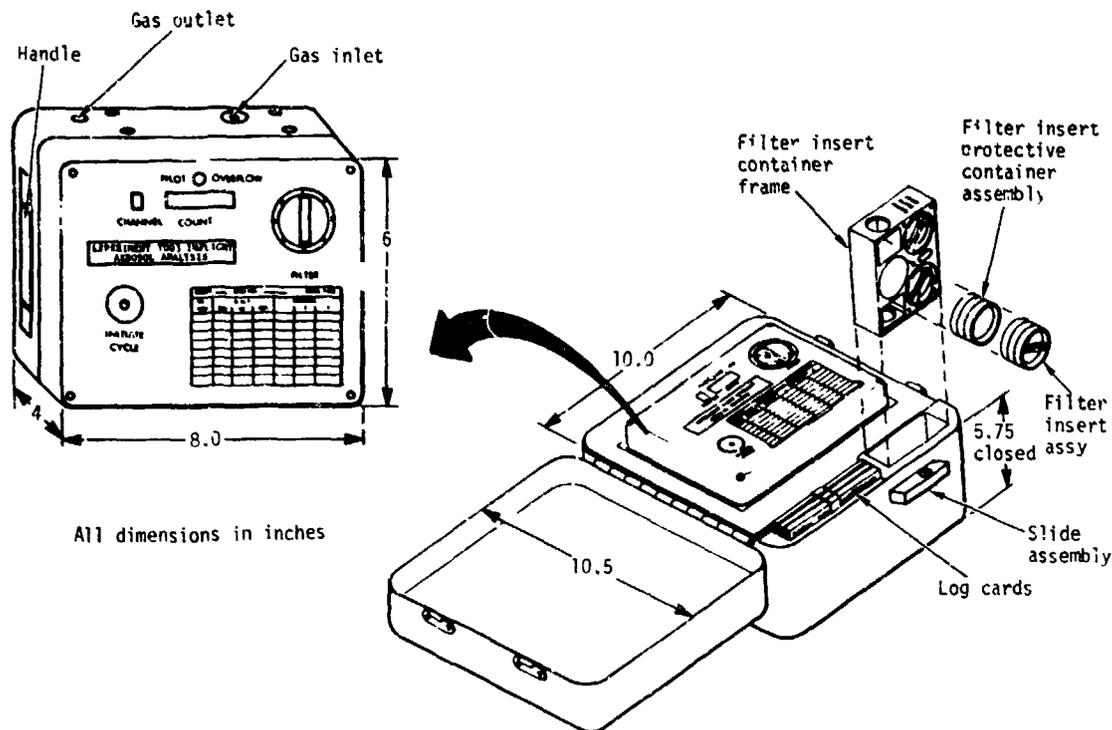


Figure 12-48.- Inflight aerosol analysis experiment particle collector.

The experiment was operated during all manned periods at the designated locations. The crew tasks associated with operating the equipment and the locations were arranged and categorized into functional objectives. These objectives were scheduled into the daily flight plan. The crewman would operate the equipment and record the results on the experiment log card. The equipment was operated on 153 of the 172 days that Skylab was manned, for a total of 390 times. The experiment equipment performed well. The crewmen's comments pertinent to the operation, performance, and handling of the hardware were consistently favorable. At the conclusion of each manned period, the used filter and the log cards were returned to Earth. Three filters and 25 log cards were returned.

#### 12.4.6 Crew Vehicle Disturbances (T013)

The crew vehicle disturbances experiment (T013) measures the torques, forces, and vehicle motions produced by the crewman's body movement and determines the effects of these items on the attitude and control of the vehicle.

The hardware consists of devices to measure the body motions of a crewman and the forces he applies to the workshop while making these motions. It consists of three systems: a limb motion sensing system, a force measuring system, and a data system. Onboard motion pictures, using the 16-millimeter data acquisition camera, are obtained concurrently with the experiment operation. The limb motion sensing system (fig. 12-49) is a skeletal structure incorporated into a suit, with pivots at the major body joints. Each pivot is monitored by a linear potentiometer which provides a continuous measurement of body limb position. The force measuring system consists of two force measuring units attached to the walls of the workshop

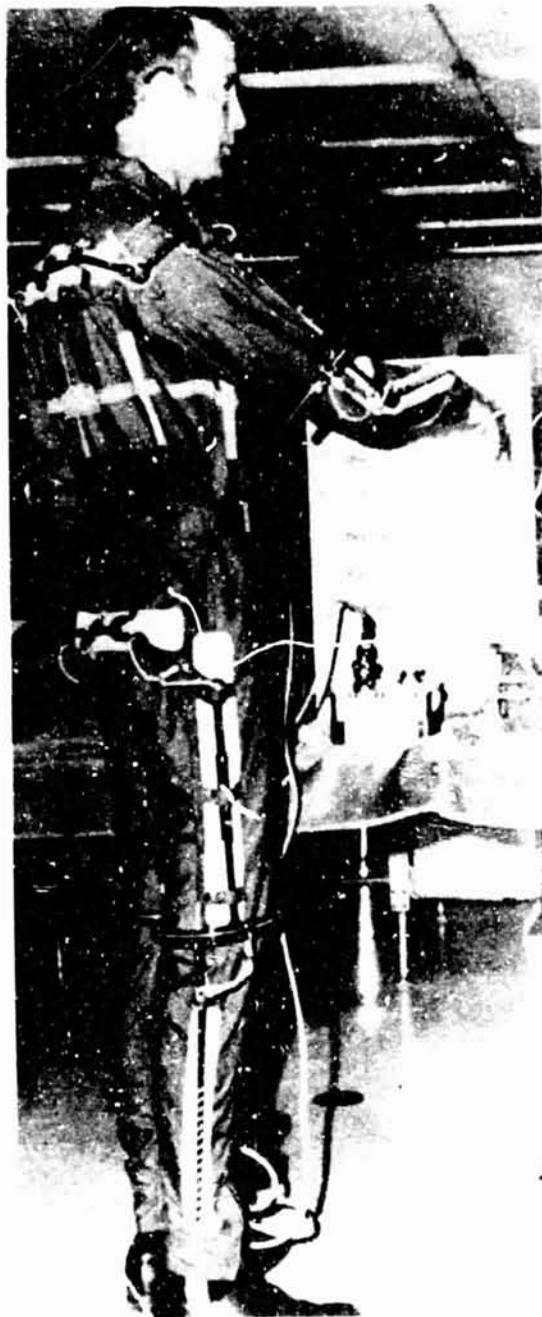


Figure 12-49.- Limb motion sensing assembly.

(fig. 12-50) that are used to measure the forces and moments applied to the workshop structure during the movements of the crewman. The data system converts the analog signals to digital data and routes them to the laboratory data system. The data are then telemetered to the ground with real-time data from the attitude and pointing control system.

The experiment was performed during the second manned period. The performance required three separate tasks:

- a. Task 1, "Gross Body Motions": While the crewman was restrained to force measuring unit 1 he made right and left arm and leg motions, torso motions, breathing motions, and sneezing and coughing simulations.
- b. Task 2, "Simulated Console Operations": The crewman simulated the operating and rotating of switches on a control panel while restrained to force measuring unit 1.
- c. Task 3, "Worst Case Inputs": One crewman performed rapid movements with arms and legs, and soared between the force measuring units. Another crewman then joined the first in performing soaring maneuvers in unison. The second crewman soared between the food locker and film vault.

The experiment was performed on Day 95. Contact with a tracking station was required so that the photographs of crew motion could be correlated with the real-time stability data from the attitude and pointing control system. The sequence began with task 3, while Skylab was over the Vanguard tracking station, and continued with tasks 1 and 2 in turn. The tasks were repeated in the same sequence until each had been performed twice. The crew did not successfully operate the data acquisition camera during

the first task 3 sequence. Because of this, a subsequent rerun of task 3 was approved. Meanwhile, telemetry records from the task 3 performance indicated that something had happened to load cells 4 and 5 of force measuring unit 2. Approximately 9 minutes after the experiment was begun, the output from these two load cells was offscale on the high side and remained there permanently. The crew performed a malfunction procedure on Day 107, and it was concluded that the load cells could not be repaired. Each force measuring unit contains six load cells. Even

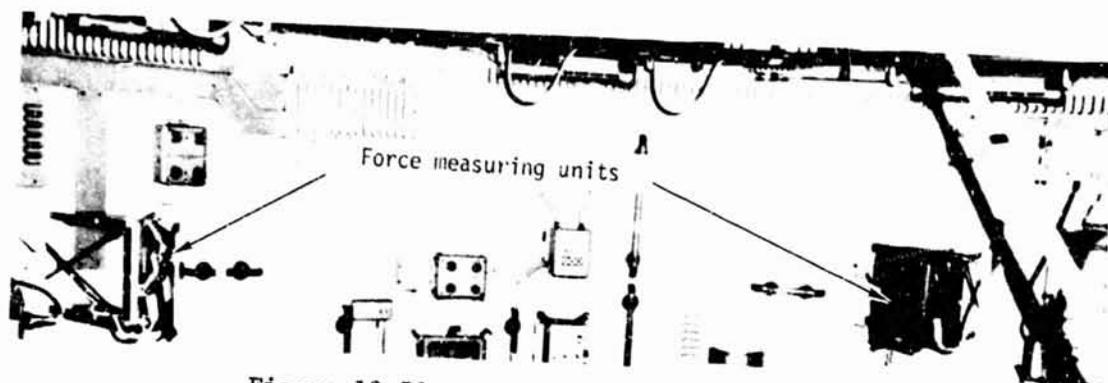


Figure 12-50.- Force measuring system.

though two load cells were malfunctioning in unit 2, there were still four from which to obtain data. The crew recalibrated the force measuring units on Day 108, and reran task 3 the next day. No data were received from this run because the electric power switch for the data system had been turned off. Task 3 was rerun again on Day 114, and its functional objectives were accomplished. Crew comments indicate that they encountered no problems in operating the experiment.

The hardware accomplished the experiment objectives. The crew required more time to perform the experiment than anticipated, but not all of the time can be charged to the performance of the hardware. The reason for the failure of the two load cells on force measuring unit 2 is unknown. The conclusion, based on telemetry data, is that the failure was caused by forces or torques higher than the design measurement range for the force measuring system. No problems were identified with the remaining hardware. There was, however, one interface problem with the laboratory data system. The laboratory data system provides a timing signal to the experiment data system so the experiment data can be correlated with the Skylab stability data. The timing signal to the experiment was out of synchronization during one run, and it was necessary to obtain the data from the experiment raw data tapes at the tracking stations.

Telemetry data representing the different forces and positions measured by the experiment hardware and the Saturn Workshop attitude and pointing control system were received. In addition, 930 feet of S0168 colored motion picture film, crew log books, and crew voice transcripts were returned.

#### 12.4.7 Foot Controlled Maneuvering Unit (T020)

The foot controlled maneuvering unit experiment (T020) evaluates an unstabilized crewman maneuvering device which is controlled by the crewman's feet. The crewman is secured on a support structure that contains propulsion and control devices. His locomotion is provided by ambient-temperature compressed nitrogen gas that is fed to thrusters below and outboard the crewman's feet. The propulsion gas is contained within a tank located on a backpack which is strapped to the crewman's back. Figure 12-51 shows the hardware in the operational mode.

The hardware consists of the support structure, backpack, and harness assembly. It shares the propellant supply system and electrical battery with the astronaut maneuvering equipment experiment (M509). The support structure contains a saddle on which the crewman sits. At the base is a cross member that contains the control pedal for each foot. Outboard of the cross member, on each side, is

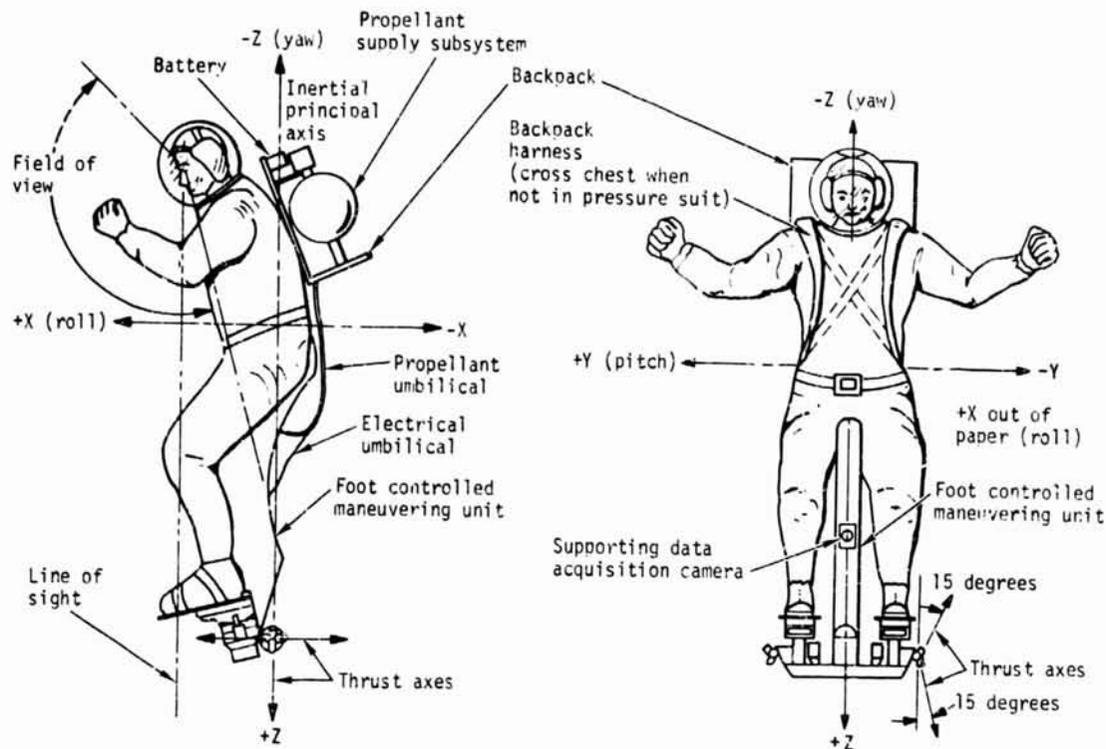


Figure 12-51.- Foot controlled maneuvering unit operational configuration.

mounted a quadruple thruster assembly where the thrust originates. Movement of the foot controls the firing of the thruster. The backpack contains the battery and the propellant supply subsystem. The electric power and propellant gas are fed from the backpack to the support structure through umbilicals. The harness assembly restrains the crewman to the support structure. Both the battery and propellant supply are rechargeable.

The foot controlled maneuvering unit was operated inside the workshop on Days 98, 108, and 123 during the second manned period and on Days 247 and 256 during the third manned period. The operation on Day 123 was the only one with the crewman wearing a pressure suit; other operations were performed with the crewman wearing normal clothing. A motion picture camera mounted on the support structure used a split image mirror system to provide location data on the experiment. A second camera mounted in the dome of the workshop provided an overview of the entire operation.

The first time the maneuvering unit was operated, the crewman reported difficulties with the restraint harness loosening so that it did not hold the crewman securely to the unit. The difficulty was not severe enough to terminate the experiment, and the prescribed maneuvers were satisfactorily completed. During consultations between the crew and experiment representatives, a modified restraining harness was rigged by the crew using onboard straps. The modified harness showed such improvement that a modification kit containing additional straps and brackets was sent up and installed during the third manned period. During the suited run the crewman had difficulties in keeping his feet in the foot restraints and in being able to see in the direction of his feet. Evaluation of the returned photographs verified that these difficulties were caused by improper harness adjustment which resulted in the crewman leaning back further than desired.

During the second manned period the crewman reported that the control input forces seemed excessive. He noted that the forces were much higher than those used during normal day-to-day translations within the workshop. During the third manned period the crewman considered the input forces satisfactory and within the range expected. He did have minor difficulty in commanding the left toe-up inputs and attributed this to a coordination problem, unique to himself, and accentuated by muscle tone changes after 70 days of space flight. The crewman operating the experiment and the crewman observing the experiment made voice recordings about the experiment performance, and these were returned as part of the experiment data. Approximately 965 feet of 16-millimeter color film and 15 still photographs were obtained. In addition, onboard television recordings of selected operations were made.

#### 12.4.8 Contamination Measurement (T027)

The contamination measurement experiment (T027) measures the contaminants of the environment surrounding Skylab. Two instruments are used: a sample array that collects contaminant deposits on various samples, and a photometer that measures the sunlight reflected from particles surrounding Skylab. The photometer was shared with the gegenschein and zodiacal light experiment, S073 (12.2.2). The photometer system and the sample array are individual, independent instruments. Both items are extended through the scientific airlock for operation; each has its own extension mechanism. The photometer system has a universal extension mechanism which is also used to extend the particle collection experiment (S149) and a television camera outside the workshop. This extension mechanism uses a tripod that fastens to the floor of the workshop. The tripod was used for deployment of the parasol thermal shield, and the backup tripod that was sent with the first crew was used for the experiment.

Sample Array.- This instrument uses quartz crystal microbalance assemblies and optical property samples of various windows, mirrors, and diffraction gratings. The instrument exposes the samples for controlled periods of time to the space environment surrounding Skylab. Two quartz crystal microbalances and 48 samples of 16 different types are exposed. The instrument is shown in figure 12-52). Motor driven, automatically sequenced carousels are located beneath the upper and lower face plates. Holes in the face plates allow sequential exposure of the samples mounted on the carousels. A valve cover plate over the holes in the forward face plate seals the array when it is retracted. At the end of the exposure period, the sample array is retracted and sealed in space vacuum for return to Earth for analysis and study. Telemetry data are obtained from the microbalance while it is exposed.

The instrument was deployed on Day 35 and was retracted 46.5 hours later during the first manned period. It was scheduled to be deployed through the +Z scientific airlock, but was rescheduled for the -Z scientific airlock after the first was blocked by the parasol thermal shield. The changing of scientific airlocks meant there would be no telemetry from the experiment and temperatures experienced would be approximately 100°C colder. The array was deployed even under these conditions because it was estimated that 80 percent of the objectives could be attained even if telemetry data from the microbalances were unavailable and if both carousels cold-seized. When the instrument was removed from the scientific airlock, a crewman noticed that the upper carousel valve was not seated. The cold instrument frosted over in the workshop atmosphere. When the unit warmed up, the crewman was able to seat the valve fully.

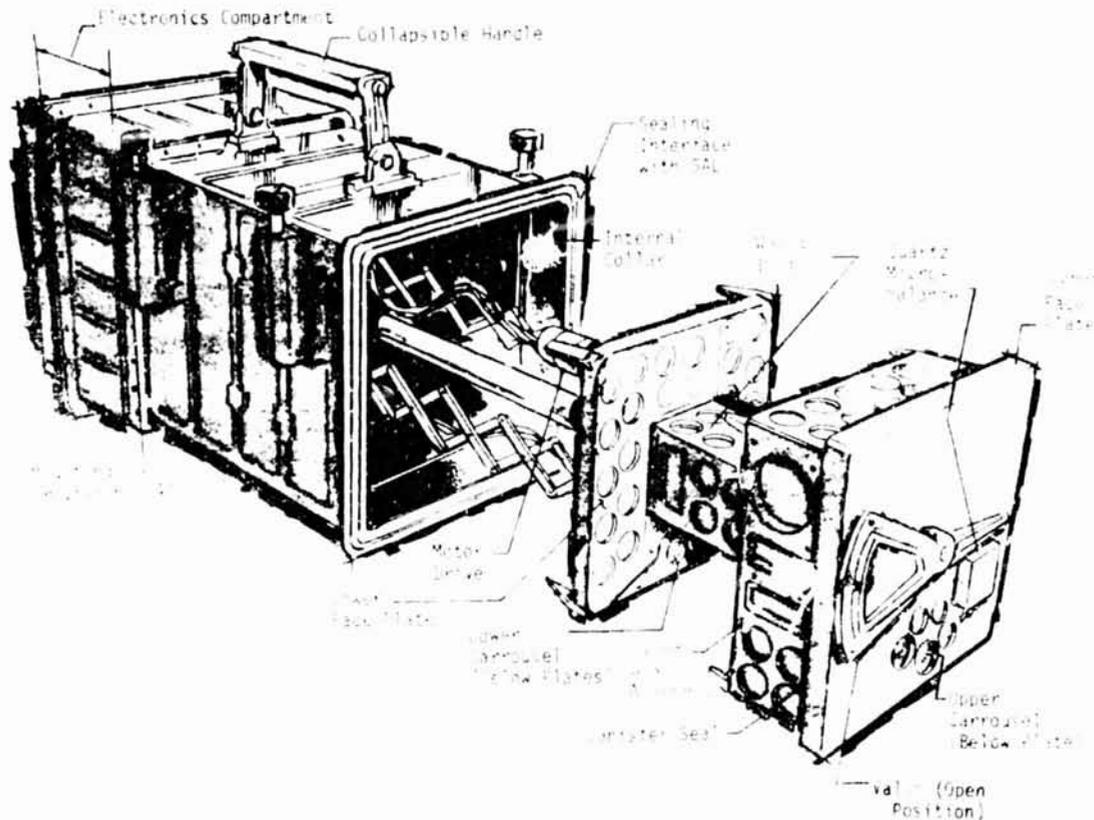


Figure 12-52.- Sample array extended.

The sample array was operated under abnormal conditions. The change in scientific airlocks affected the experiment severely. The  $-62.2^{\circ}\text{C}$  temperatures experienced was much colder than the  $55^{\circ}\text{C}$  temperature the instrument was designed for. The minimum qualification temperature was  $-18^{\circ}\text{C}$ . Without telemetry, no data were obtained from the quartz crystal microbalance assemblies. In addition, there could be no verification that the carousels were indexing at the prescribed times. The sample array was supposed to be deployed on Day 4 and to be exposed for 120 hours; it was deployed on Day 35 and was exposed for 46.5 hours. The later deployment and shorter exposure times resulted in operation while outgassing rates and deposition levels were lower. The cold temperature caused the valve in the forward faceplate to cold-seize and remain open until it thawed out in the workshop. This allowed the workshop atmosphere to enter the sample areas and violate the requirement for space vacuum sealing.

The instrument was returned for analysis of the samples. Preliminary analysis indicates the daily carousel did not index and the hourly carousel either did not index or had completely indexed (the initial and final positioning of the hourly carousel are the same). Contamination analysis of the samples did not reveal conclusively whether they were exposed or not. Arrangements have been made for the principal investigator to obtain portions of the returned thermal control coatings (D024), particle collection (S149), and magnetospheric particle composition (S230) experiments as substitutes for the data he lost on his experiment.

**Photometer System.**— This instrument measures the amount of light in its field of view for two separate purposes. It measures the sky brightness caused by solar illumination of contaminant particles for the contamination measurements experiment (T027) and the brightness and polarization of the skyglow for the gegenschein and zodiacal light experiment (S073). Both measurements are made during the same operation of the instrument--the contamination measurements experiment (T027) primarily in sunlight while entering or leaving the Earth's shadow, and the gegenschein and zodiacal light experiment (S073) primarily while in the dark portion of the orbit.

The primary elements of the photometer system are the canister and extension mechanism, automatic programmer, and photometer head (fig. 12-53). The canister

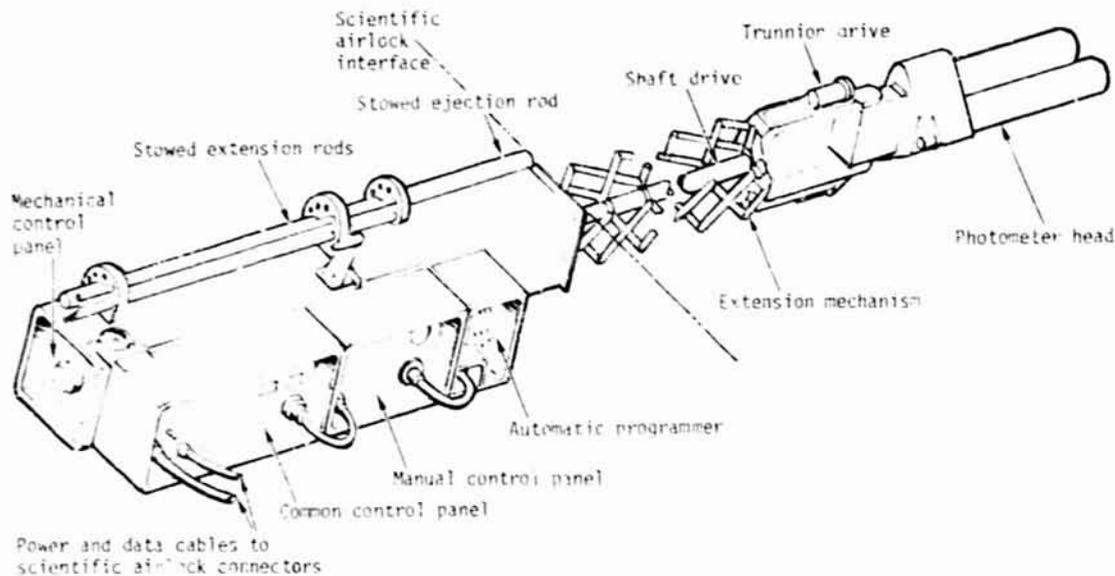


Figure 12-53.— Universal extension mechanism with photometer.

and extension mechanism are the primary structural, extending, and jettisoning elements. Seven extension rods provide manual extension up to 18 feet beyond the workshop. The extended item can be motor driven 112 degrees in the trunnion position (elevation) and 354.4 degrees in the shaft position (azimuth). The automatic programmer controls the automatic operation of the photometer head and pointing system. Seven different scanning or control modes can be selected. The photometer head contains a photoelectric polarimeter and a 16-millimeter data acquisition camera. The polarimeter measures the integrated light of all sources entering the adjustable field of view. It contains lenses, a photomultiplier tube, filters, polarizers, a calibration source, and temperature sensors. The field of view is adjustable to 1, 3, and 6 degrees. The laboratory data system samples the photometer data at 220 samples per second. The data acquisition camera photographs the various starfields and other light images. It has a field of view of approximately 15 degrees collinear with and overlapping that of the polarimeter. Camera sequencing is interrelated with the pointing system, thereby providing exposures at differential intervals. The camera focus and aperture are fixed, but two exposure durations are used, depending on the light levels.

The constraint to use only the -Z scientific airlock impacted about six scans related to solar observatory experiment contamination and inner zodiacal light at the point where this light begins to blend into the outer solar corona. Thus a

new scanning program was implemented. The photometer system was installed and first used on Day 29. It had a minimum scheduling requirement of nine scans. It made 11 scans in 6 days and gathered photographic and telemetry data for approximately 15 hours. The 11 scans were not performed exactly as called for in the requirements because the Moon and planet locations were different from those planned for and because priorities were revised as the mission progressed.

The universal extension mechanism was used to expose the particle collection experiment (S149) from Days 38 to 80. The photometer was again installed and deployed on Day 80. A minimum of 10 scans were required for this second manned period. The next day, a malfunction made it impossible to retract the photometer, so the photometer and extension mechanism had to be jettisoned overboard. No 16-millimeter photographs were obtained during this period because the camera, too, was jettisoned. Approximately 6 hours of telemetry data was obtained, however, before the photometer was jettisoned. Later during this period, the crew rigged the coronagraph contamination measurements hardware and the ultraviolet airglow horizon photography camera and took seven exposures. These pictures were so successful that this combination was used for the third manned period, on a low priority basis. During the third manned period, 17 night passes were required to obtain 85 photographs. The 17 night passes produced 96 photographs, a gain of 11 photographs. One 140-foot magazine of 16-millimeter film, telemetry, and 103 35-millimeter photographs were returned for those experiments that used the photometer system.

The inability of the photometer to retract was classified as an anomaly. The photometer head could not be changed from the shaft position of 354.4 degrees on Day 81. The photometer must be in a shaft position of either 45, 135, 225, or 315 degrees for it to be retracted into the workshop. Two days were spent trouble-shooting and performing malfunction procedures, in an effort to retract the photometer. All procedures were unsuccessful, and the photometer and universal extension mechanism were jettisoned overboard on Day 83. Jettisoning was necessary to clear the scientific airlock so it could be used by other experiments. The remaining canister assembly was stowed.

The malfunction was caused by the failure of a circuit element which kept a relay from operating. Circuit analysis of the motor drive logic circuit, shaft drive relay circuit, and input elements showed that the design was adequate and that no weak elements existed. The circuit element that failed had a rather long failure transient time of 6 hours. During this period, the failed element was overloading the 5-volt power supply and causing the 5- and 29.5-volt power supply to drop out when the low regulation limit of 4.6 volts was exceeded. After the transient period, the shaft motor drive circuit was completely open. The failure of the element can be classified as random in nature. The specific element that failed is not known, but its location is believed to be either in the common panel or in the relay and driver assembly. The units that contained the suspected failed element remained onboard Skylab.

The loss of the photometer system and universal extension mechanism hampered the performance of three experiments. The contamination measurements (T027) and gegenschein and zodiacal light (S073) used the photometer system to measure contamination and zodiacal light. The particle collection experiment (S149) used the universal extension mechanism, which was also lost. The use of coronagraph contamination measurements (T025) and ultraviolet airglow horizon photography (S063) hardware to gather data for the contamination measurements (T027) and gegenschein and zodiacal light (S073) experiments minimized the loss to the latter experiments. In addition, the particle collection (S149) hardware was deployed

outside the workshop by the crew during extravehicular activity for 47 days of exposure.

#### 12.4.9 Proton Spectrometer

The proton spectrometer obtains the data necessary for mapping such radiation areas as the South Atlantic Anomaly and the portions of the Northern and Southern horns that Skylab passes over. The proton spectrometer consists of a detector head assembly and an electronics subsystem (fig. 12-54). It is installed on a truss at the forward end of the docking adapter. The instrument

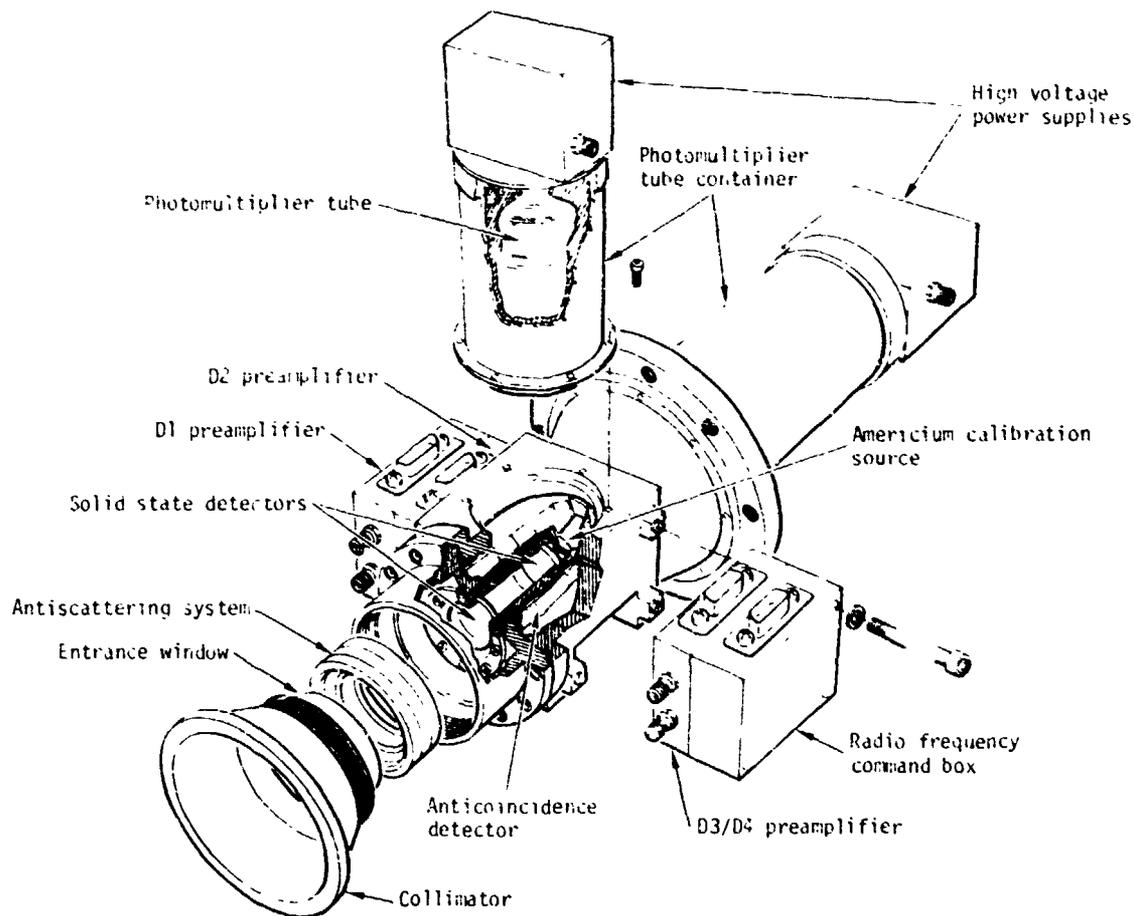


Figure 12-54.- Proton spectrometer detector head assembly.

measures and classifies electrons from 1.2 to 10 MeV and protons from 18.5 to 400 MeV. The detector head is a directional device composed of four detectors. Three detectors (D1, D2, and D3) are used to detect the presence and energy of the particles. A fourth detector (D4) surrounds these detectors and is used as an anticoincidence detector to create a 45-degree acceptance cone and to measure the total flux of the radiation field (fig. 12-55). The electronics subsystem processes the data from the detectors and presents them to the laboratory data system. The processing determines if the particle entered the instrument through the 45-degree acceptance cone and if it is an electron or a proton. It then determines the particle's energy and adds it to the appropriate counter. The instrument has 12 digital channels and 4 analog measurements. The data are

transmitted to the ground station directly or recorded onboard for subsequent

transmission, thus enabling reconstruction of an entire orbit. Real-time monitoring of the data is limited to the four analog measurements.

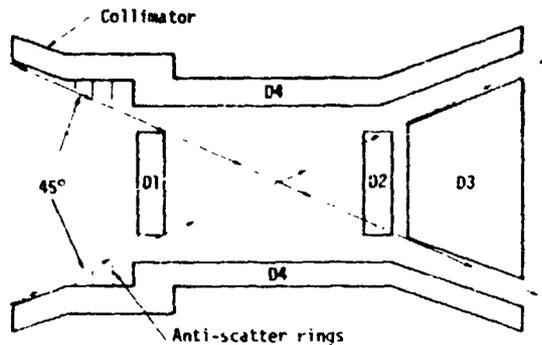


Figure 12-55.- Detector orientation.

Two constraints are imposed on the proton spectrometer. A temperature constraint specifies that power shall be applied to the instrument anytime the instrument's temperature approaches  $-25^{\circ}\text{C}$ . A corona constraint specifies that the instrument shall be turned off during command and service module reaction control system thruster operations, including docking and undocking.

The proton spectrometer was exposed to the space environment when the shroud was jettisoned. The instrument was turned on by ground command approximately 12 hours after launch. Activation was supposed to occur approximately 4 hours after launch, but this was delayed to conserve power.

The first data from the proton spectrometer were received approximately 5 hours after it was turned on. The peaking of the total flux measurement detector was monitored in real time. The first digital data were received approximately 23 hours after spectrometer activation. These data and those from subsequent passes which were going into or coming out of the Northern Horn Belt showed that two electron channels and all proton channels were not operating properly. Subsequent investigation found that this indication was caused by a temperature-induced failure. The instrument was cycled off and on throughout the mission in an effort to restore proper operation, but without success. It was operated throughout the Skylab mission even though some of the data were degraded. The data were telemetered throughout the mission and stockpiled for subsequent analysis. The constraint to turn power off during reaction control system thruster operations was cancelled on Day 38. Because the instrument was experiencing colder temperatures than expected ( $-32^{\circ}\text{C}$  instead of  $-10^{\circ}\text{C}$ ), there was more concern about the cold temperature's further damaging the instrument if it were turned off than there was about corona if the instrument were left on during thruster operation.

A temperature-induced failure in the instrument caused the outputs of all 8 proton channels and 2 of the 3 electron channels to be degraded; thus 10 of the 12 digital channels did not provide data as expected. It has subsequently been determined that a design error was made in the emissivity value of the thermal shroud of the instrument. The value of 0.05 was used in the thermal model rather than the correct value of 0.88. The first data received from these channels revealed that the problem existed, so the exact time of occurrence is unknown. The temperature of the instrument was  $-25^{\circ}\text{C}$  when it was turned on 8 hours later than planned, and the temperature constraint would have been violated had the instrument not been turned on at that time. The data from the remaining channels are good. From these it will be possible to measure the total flux levels and dosage levels encountered. Different methods for processing the degraded data from the affected channels are being explored in an effort to obtain the most information possible.

## 12.5 STUDENT INVESTIGATIONS

The Skylab Student Project was designed to involve in the space program young people who possess an interest in science and technology and to foster this interest through direct participation in the Skylab program.

To implement the Skylab Student Project, the National Science Teachers Association was requested to sponsor, organize, and administer a national competition for high school students. Twelve geographic regions were designated, each with a regional chairman appointed to receive all proposals for his region. The regional chairman in turn appointed a committee to evaluate each proposal. A total of 3409 proposals were submitted by students; however, because of team proposals, more than 4000 students participated in proposal submittals. Three hundred proposals were selected from the 12 geographic regions. From these 300 regional winners, 25 national winners were selected. The 25 winning students were each assigned a science advisor to aid with the preparation and evaluation of his experiment in terms of compatibility with, and constraints of, the Skylab program.

At a preliminary design review in May 1972, a review board determined that 19 of the 25 proposed experiments could be flown. Of these, 11 required hardware development and 8 used the hardware and data of other experiments. The remaining 6 of the 25 selected experiments were incompatible for flight on Skylab, but were recognized as possessing considerable merit. Arrangements were made for these six students to be associated with scientists in alternate, corollary research programs to keep them involved in space science activities. Four of these six are discussed at the end of this section. The other two, colloidal state (ED71) and powder flow (ED73), are not included since the assigned alternate activities were not related to Skylab.

Experiments were implemented by associating the student investigator with a Skylab principal investigator who then supported the student investigator's requirements. Experiment hardware was developed at Marshall Space Flight Center. During the mission, the student investigators were actively involved in following the conduct of their experiments or related experiments. After the mission, it is the responsibility of the student investigator to submit a formal report of his experiment covering both ground-based and in-orbit operations. The report must also reflect an independent analysis by the student of all experiment data derived from the performance of his experiment.

### 12.5.1 Atmospheric Attenuation of Radiant Energy (ED11)

The atmospheric attenuation of radiant energy experiment (ED11) determines the attenuation of energy in the visible and near-infrared spectral regions through the Earth's atmosphere at various locations and under varying atmospheric conditions. The attenuation is determined for solar radiation and for energy reflected from the Earth's surface.

Data obtained by three instruments used for the Earth observations and data obtained at selected Earth surface sites are used in the investigation. The infrared spectrometer (S191), obtains data in the 0.4 to 2.4 micron spectral band, with concurrent synoptic photographic data being acquired by the multispectral photographic facility (S190A), and the Earth terrain camera (S190B). The photographic data are further supplemented by tracking photography from the onboard Earth observation viewfinder-tracker, which provides a plotting base for the infrared spectrometer data. Ground data include direct, total, and diffuse solar radiation

measurements obtained with pyroheliometers and pyronometers. Reflected radiation is measured with similar instruments. Figure 12-56 shows the pointing range of the infrared spectrometer relative to the ground target site.

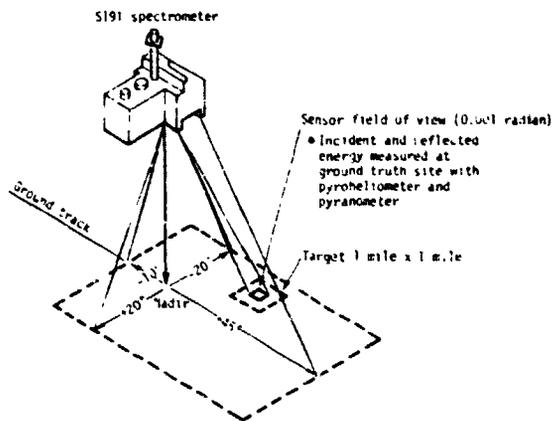


Figure 12-56.- Infrared spectrometer pointing range.

Figure 12-56 shows the pointing range of the infrared spectrometer relative to the ground target site. Ground target sites are located at the Houston, Texas, and White Sands, New Mexico, areas and at the Four Corners area (junction of Colorado, Utah, Arizona, and New Mexico). Experiment objectives are satisfied through analysis of the same data obtained by Earth observation experiments.

During the first manned period, passes were made on Day 23 over the Houston area and on Day 32 over the White Sands area. In the Houston pass, extensive cloud cover precluded sensor operation, but on the White Sands pass, a hole in the cloud cover was found and it is assumed that some data were obtained. During the second

manned period, data were not obtained during several attempts over assigned sites because of a westward shift in the ground track. On Day 116, usable data through unpolluted and polluted atmospheres were obtained at Phoenix, Arizona, a previously unassigned task site. During the third manned period, passes were made over the Houston area on Day 202 and over the White Sands area on Days 206 and 207.

Data obtained included Earth observation experiment photographs recorded at 684 samples per second to a 10-bit quantization. These data were reduced and provided to the student investigator in a tabular presentation of radiation intensity versus wavelength. The ground site data acquired were also provided.

#### 12.5.2 Volcanic Study (ED12)

The volcanic study experiment (ED12) examines the feasibility of predicting volcanic activity through remote thermal infrared sensing. Active volcanoes are monitored from Skylab using the infrared spectrometer (S191), the multispectral scanner (S192), the multispectral photographic facility (S190A), and the Earth terrain camera (S190B). Emitted thermal radiance is monitored in the 6.2 to 15.5 micron region by the infrared spectrometer. The multispectral scanner senses thermal infrared energy in the 10.2 to 12.5 micron region. The cameras provide high quality multispectral synoptic photography in 70-millimeter format. The investigation uses duplicates of Earth observation data except that the infrared spectrometer obtains data specifically for the volcano study while in the crew tracking mode. The sites selected are in Nicaragua at Concepcion, Masaya, Cerro Negro, and Telica.

The experiment was performed during all manned periods. On Day 32, a pass was made over the Nicaraguan volcanic region, but cloud cover was too heavy to permit satisfactory viewing. Several subsequent attempts were hampered either by cloud cover or by the crew's difficulty in identifying the volcanoes. On Day 130, the crew reported that Mt. Etna, in Sicily, was smoking. On Day 131, a satisfactory data pass was made over Mt. Etna. Additional passes were made over the

Nicaraguan volcanic region on Days 206 and 235. The returned data consisted of photographs and recorded binary digital data having 10-bit quantization at 684 samples per second and other binary digital data having 8-bit quantization at 1240 and 2480 samples per scan. The photographic data were provided to the student investigator in a format and scale suitable for use in plotting thermal contours. The thermal infrared data were provided in a form that could be superimposed on the photographic data. Correlative ground data, where available, were also provided.

### 12.5.3 Libration Clouds (ED21)

The libration clouds experiment (ED21) studies the lunar libration cloud regions at the Lagrangian points  $L_4$  and  $L_5$ . Figure 12-57 shows the Earth-Moon gravity force contour pattern and the location of the libration cloud regions and the zero force fields. The white light coronagraph (S052) is used to observe and

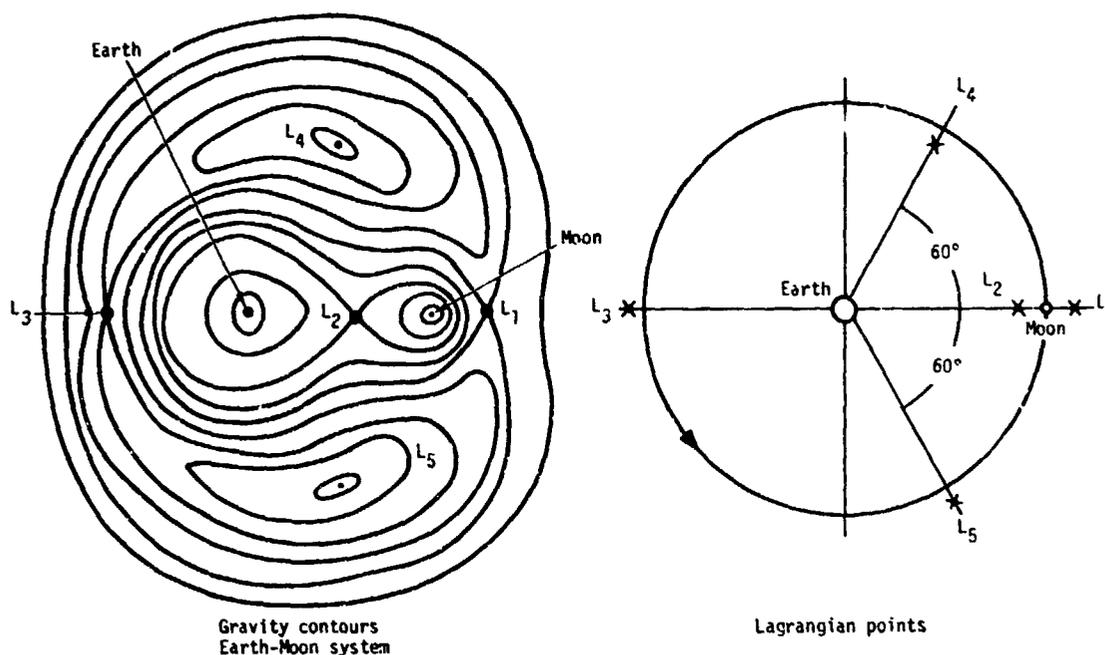


Figure 12-57.- Gravity contours and Lagrangian points.

record the existence of dust cloud accumulation in lunar libration regions and the variation in size or brightness as a function of orbital position. The requirements of the libration clouds experiment are met with duplicates of data produced by the white light coronagraph experiment. During orbits where the libration cloud regions are within the field of view, additional white light coronagraph data are obtained as solar conditions and film supply permit.

Film data of the  $L_5$  Lagrangian point were obtained during the first manned period. Similar photographs were obtained during the second unmanned period on Days 52 and 53. No observations were made during the second manned period except for an unattended filming of the  $L_4$  point on Day 77. During the third manned period, observations were made of the  $L_4$  point on Day 219, and a partial observation was made on Day 251. Returned data consisted of white light coronagraph photographs of the observed lunar libration points.

#### 12.5.4 Objects Within Mercury's Orbit (ED22)

This experiment observes for possible bodies in orbit between Mercury and the Sun. Figure 12-58 shows the postulated solar orbit of an intra-Mercury-orbit body and the regions where Skylab observations are made that will satisfy the experiment. The white light coronagraph (S052) provides the required observational capability, and synoptic photographic data obtained without modification to hardware or procedures are duplicated for this student investigation.

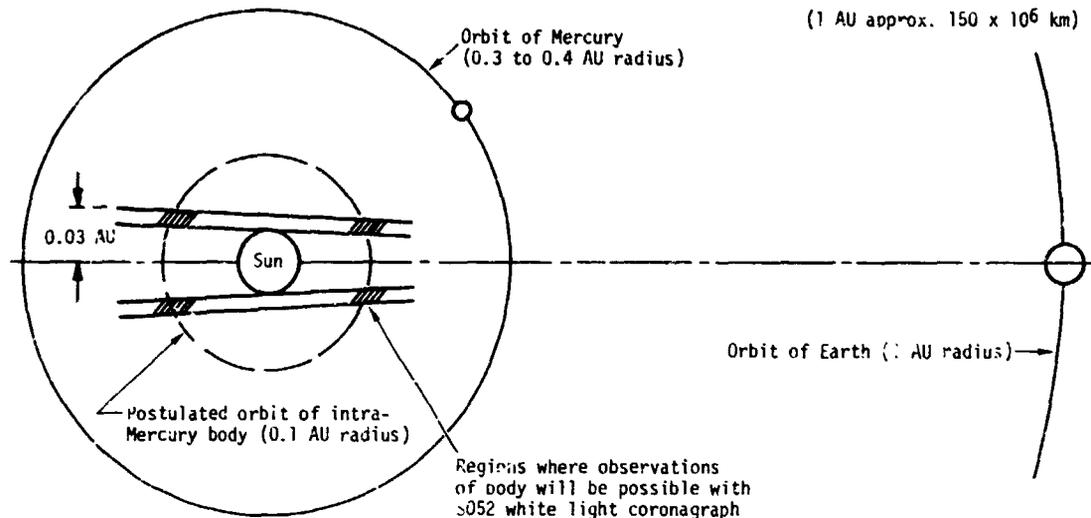


Figure 12-58.- Observation regions.

Synoptic observations of the Sun were planned to occur throughout the entire mission on a daily basis. During the first manned period, 31 observations were performed. Several days were lost while a failed photographic camera was being replaced. During the second unmanned period and second manned periods, all planned observations were carried out, and 9737 frames of film were acquired. During the third manned period, synoptic observations of the Sun were performed on an average of 4 times a day, and 12,547 frames of film were acquired. It is not yet known how many of the exposed film frames contain observations of the desired orbital region. Very few opportunities for synoptic photography were missed.

#### 12.5.5 Quasars (ED23)

The quasar experiment (ED23) obtains spectra of selected quasars and Seyfert galaxies in the ultraviolet spectral region. The ultraviolet stellar astronomy instrument (S019) is used to perform the investigation. The instrument's prism and widening mechanism are not used. Figure 12-59 shows the instrument installed in the scientific airlock. One dark side pass of 32 minutes duration while the Moon is at less than half phase is performed. Saturn Workshop venting and attitude maneuvers are constrained before and during performance of this experiment. A list of possible targets, including pointing and priority information, is provided to the crew. Three 30- or 90-second exposures of each target are required. One exposure is focused on the target, one exposure is offset 1 degree in tilt, and one exposure is offset 1 degree in rotation.

During the first manned period, on Day 28, the data pass for this experiment was performed when the Moon was nearly full. Photographs of Quasar 3C273 and

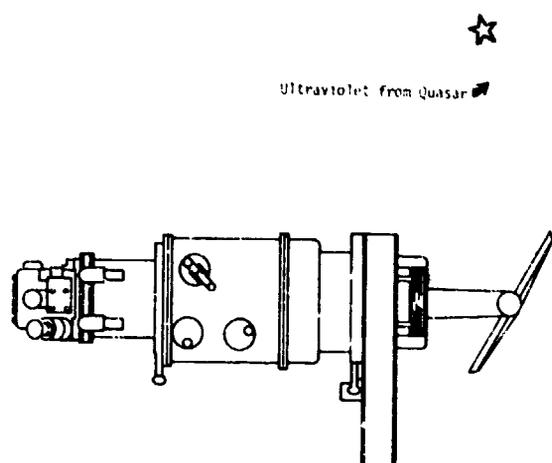


Figure 12-59.- Ultraviolet stellar astronomy instrument mounted in scientific airlock.

Seyfert galaxy NGC7469 were taken, and acquisition of Seyfert galaxy NGC5548 was attempted. During the second manned period, a photograph of the M7 cluster was made for calibration purposes, and attempts were made to photograph two Seyfert galaxies, NGC1068 and NGC1275. Pointing was in error, however, by 3 degrees. Further performance was scheduled for the third manned period, but considerable demand on the ultraviolet stellar astronomy instrument for the support of other corollary experiments precluded its further use for the quasar experiment. The returned data were the photographs obtained. Some useful data are expected from the pass during the first manned period despite violation of the Moon phase constraint. No data were obtained from the other attempts.

#### 12.5.6 X-Ray Stellar Classes (ED24)

The X-ray stellar classes experiment (ED24) determines the location of stellar sources and the relationship between the age of a star, the spectral class, and the intensity of emitted X-rays. The investigation uses duplications of data from the X-ray spectrograph experiment (S054). The X-ray spectrograph film camera provides the required photographic data of SC0 X-1 or alternate stellar X-ray sources. During the third manned period, three attempts were made to acquire stellar X-ray data. However, the X-ray spectrograph instrument, which was designed for solar observation, was not sensitive enough to detect stellar X-rays. The returned data consisted of photographs and supportive instrument pointing data. Since stellar X-ray data were not acquired, solar X-ray photographs were provided. The student investigator will participate in a problem of data analysis and interpretation of solar X-ray data.

#### 12.5.7 X-Rays From Jupiter (ED25)

The X-rays from Jupiter experiment (ED25) obtains X-ray emission data from the planet Jupiter and investigates for correlation of X-ray emission with solar activity and Jovian decametric radio emission. Additionally, X-ray emission data are sought from a neutron star possibly present in the Cygnus Loop. The investigation uses data acquired by the X-ray spectrograph (S054). Jovian observations are scheduled as dictated by solar flares and related geomagnetic activity. In the absence of a large solar flare, observations are conducted any time Jupiter is observable. If data from Jupiter are not obtained, stellar X-rays from the Cygnus Loop are observed. It is mandatory that at least one reference star be accessible to the star tracker during the experiment maneuver period to provide the required pointing accuracy.

The experiment was performed during the third manned period. It became evident that the instrument was not sensitive enough to record the relatively slight intensity of Jovian X-rays. Operational constraints developed that precluded observation of the Cygnus Loop. No data were returned on either of the selected targets. The student investigator will be permitted to carry through a study program on solar X-ray phenomena.

### 12.5.8 Ultraviolet From Pulsars (ED26)

The ultraviolet from pulsars experiment (ED26) investigates pulsar spectra in the ultraviolet region. The ultraviolet stellar astronomy instrument (S019) is used to perform the investigation during a dark side pass of 32 minutes duration, while the Moon is in the dark phase. The instrument's prism and widening mechanism are not used. Saturn Workshop venting or attitude maneuvers are avoided before and during performance. A list of possible targets, and pointing and priority information, are provided to the crew. Three 30- or 90-second exposures of each photographed target are required. One exposure is focused on the center of the target and the others are offset.

Because of improved prime target availability, the experiment was performed during the second instead of the first manned period. On Day 96, an ultraviolet stellar astronomy pass was dedicated to this experiment. The targets photographed were Scorpius, HZ Hercules, and Cygnus X-1 X-ray stars, and one as yet unnamed radio star. The corresponding ultraviolet stellar astronomy experiment star field designators for these targets are ED261, ED264, ED2611, and ED2615. The returned data consisted of the photographs of the experiment target star fields. Corollary pointing data were provided.

### 12.5.9 Bacteria and Spores (ED31)

The bacteria and spores experiment (ED31) determines the effects of the Skylab environment, particularly weightlessness, on the survival, growth rates, and mutations of bacteria and spores. The experiment equipment comprises 15 Petri dishes containing growth media and a 16th Petri dish containing five strains of living bacterial forms. A container pressurized at 5 psia holds a sterile plastic bag to contain the Petri dishes and a sterile forceps. Additional equipment includes a 35-millimeter still camera and film, an incubator, and a food chiller.

Nine inoculated Petri dishes are incubated for 48 hours at 35°C. Six inoculated Petri dishes are exposed to the Saturn Workshop ambient temperature for 48 hours. Performance was scheduled for the last 7 days of the manned period. A still photograph of each dish is obtained from each of five photographic sessions. After the final session, the dishes are stowed in the food chiller at  $5 \pm 3^\circ\text{C}$ , using a medical support system resupply container. The experiment is performed on the medical support system worktable in the workshop. Each Petri dish of agar is implanted with an inoculum disk, using the sterile forceps. The transparent cover of each dish is installed for the remainder of the experiment. The required photographic sessions are conducted at approximately equal intervals. At the conclusion, the dishes are stowed to await transfer and return on the command and service module.

The experiment was started on Day 21, during the first manned period, and completed on Day 24. The crew reported a slow microbial growth rate, and the incubation period was then increased from 48 hours to 68.75 hours. Further, a prechilled food container overcan was used for return stowage rather than the planned medical support system resupply container. It was determined upon inspection of the returned Petri dishes that only 75 of the 2500 bacterial colonies showed any development. The experiment was reassigned for performance during the third manned period. The second performance was initiated on Day 235, earlier than specified, because of possible shortening of the mission. Again an extended incubation (88.5 hours) was performed because of the slow growth rate observed.

The 15 Petri dishes from each performance were returned. In the first performance, only 50 of the required 75 photographs were returned because of a film shortage. In the second performance, all required photographs were returned, but the images were soft. This was probably caused by the difficulty in maintaining critical focus while hand-holding the camera for closeup photography.

#### 12.5.10 In Vitro Immunology (ED32)

The in vitro immunology experiment (ED32) determines the effects of zero gravity on the antigen-antibody reaction in vitro by comparing immunodiffusion rings obtained in orbit to those obtained on the ground. The experiment hardware consists of three immunodiffusion chambers (fig. 12-60) containing agar medium and antibodies, three prefilled syringes containing serial dilutions of human antigen test inoculum, and a passive cooler in which the containers of antigens and antibodies are stored. The chambers are also used as receptacles for the inoculum and for development of a precipitin reaction. Additional equipment hardware includes a 35-millimeter still camera and film, a 55-millimeter macro lens, and an extension tube.

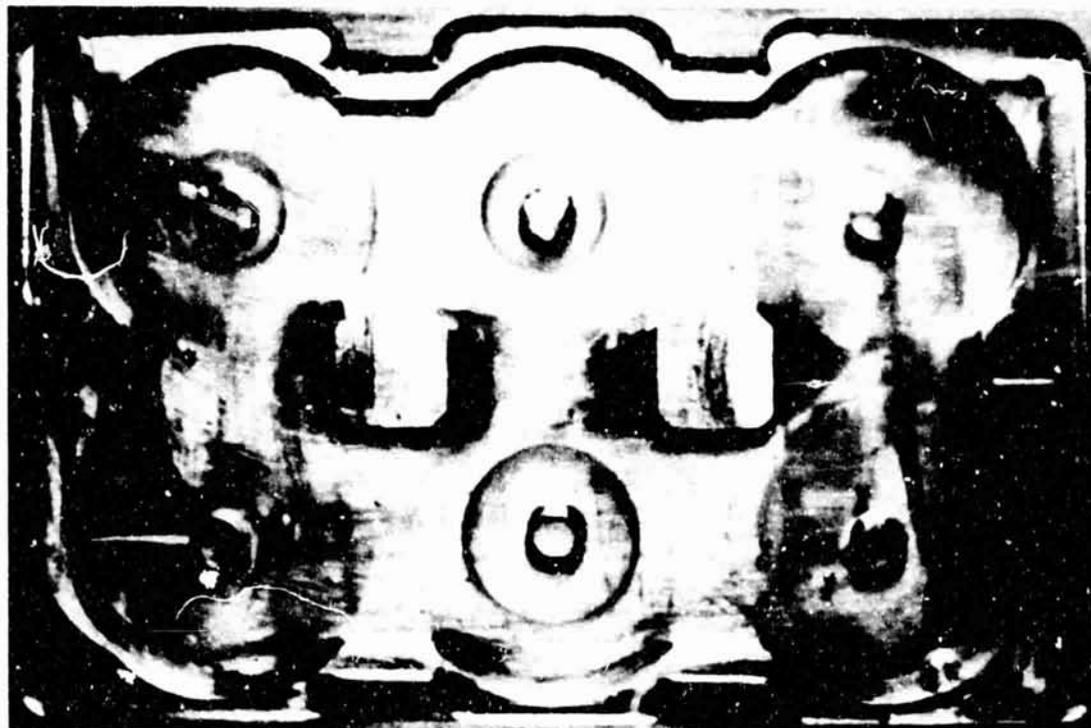


Figure 12-60.- Immunodiffusion chamber.

It is required that the inoculated plates have an incubation period of 22 hours. The resulting precipitin rings are photographed in six sessions of two photographs per plate per session with 5-hour intervals between sessions. It is required that the plates be transferred to the food chiller within 4 days after launch for maintenance at  $5 \pm 3^{\circ}\text{C}$  and that the experiment be performed within 15 days after launch. The experiment hardware is removed from the food chiller and transferred to a medical work area in the crew wardroom. The plates are removed from the passive cooler and inoculated with a measured amount of antigen from each

syringe. The plates are then stored at ambient temperature for incubation. At the end of the incubation period, the required photography is performed.

On Day 78, the experiment hardware was transferred from the command and service module to the Skylab food chiller. The experiment was deployed on Day 90. The crew reported that 5 to 10 minutes after inoculation, the agar had absorbed all of the antigen, which was normal. The crew reported on Day 93 that the final photographic sessions had been completed. They reported that "little round things" were clearly visible which grew during the 24- to 48-hour period in which photography was performed. The requirement to obtain 36 still photographs in the designated time period was fulfilled. All time constraints on storage and performance were satisfied.

#### 12.5.11 Motor Sensory Performance (ED41)

The motor sensory performance experiment (ED41) obtains human motor sensory data during prolonged weightlessness, for future mission use. The experiment hardware consists of a maze aiming and target assembly, a stylus, and a signal cable, as shown in figure 12-61. The maze is the eye-hand coordination type and contains 119 0.125-inch diameter holes in a delineated pattern. When the stylus is fully inserted into a hole, an accelerometer in the maze is shocked and a signal conditioned pulse is sent over the signal cable for input to the Saturn Workshop telemetry system. The telemetry data contain time information which permits determination of elapsed time between pulses.

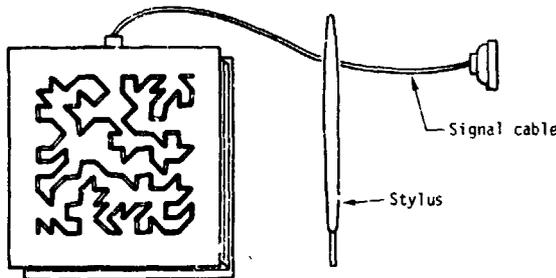


Figure 12-61.- Maze and stylus.

It is required that the experiment be performed by each crewman near the start, midpoint, and end of the manned period. The maze assembly is deployed on the workshop wardroom window shelf and the signal cable connected to a telemetry channel input at an intercom. The experiment is then performed by placing the stylus in each hole of the maze in the prescribed sequence, as quickly as possible, without the hand or forearm resting on the maze. A single performance comprises three traverses through the maze. During the third manned period, the first performance was completed on Day 196 by all three crewmen. The mid-period performance was accomplished on Day 224. The final performance was on Day 264. The experiment was performed as expected. The data returned were the telemetry data containing the time-correlated maze signal pulses.

#### 12.5.12 Web Formation (ED52)

The web formation experiment (ED52) determines the effects of a zero gravity environment on the web building process of a common cross spider (*areneus diadematus*) through comparison of webs built in orbit and on the ground.

The experiment equipment consists of two spiders, water and flies to feed the spiders, vials in a carrying case for transporting the spiders and food, an enclosure, and an automatic motion picture actuator. Experiment support hardware includes a 35-millimeter still camera and a 16-millimeter motion picture camera, with a supply of film for each. Fluorescent lamps illuminate the enclosure. The glass viewing doors of the enclosure are opened for photography, and a rigid

camera mount properly locates and orients the cameras. The camera actuator generates an ultrasonic field within the enclosure. Spider motion produces field transients which are detected and signal conditioned to actuate the motion picture camera. The camera automatically stops 10 seconds after loss of an actuation signal.

The basic requirement is to obtain a maximum of 400 feet of motion picture film of the web spinning process and three still photographs of each of three webs. The significant constraints are to deploy the experiment no later than 3 days after launch of the command and service module and to operate it for a maximum of 20 days. The experiment hardware is transferred to the workshop forward dome area. The motion picture camera is loaded and installed on the camera mount. Proper automatic camera actuator operation is verified, and the spider is deployed. Crew observations are made during the deployment and once a day hereafter. When a web is completed, the still camera replaces the motion picture camera for photography of the web as shown in figure 12-62.



Figure 12-62.- Spider and inflight web.

The spiders were stowed aboard the command and service module on Day 73. The experiment was transferred and deployed on Day 79. The automatic motion picture camera actuator would not function, so the manual mode was substituted. When the spider was shaken from its vial, it flicked its legs abnormally, and bounced back and forth within the enclosure before affixing itself to one side. On Day 85 the crew reported the first web. When planned photography was completed, the crew requested additional procedures. These were furnished, an alternate food supply was provided, and additional web formation was photographed (fig. 12-62). A completed web and the spider were stowed for return. The second spider was deployed on Day 105. It completed a web by Day 108 and was found dead on Day 126. The food supply for the first spider was replenished, but it died.

The requirement for still photographs was exceeded by the 43 pictures obtained. Motion picture film was obtained on spider deployment only. The added investigation included retrieval of web material and the spider bodies. The crew reported that the spiders did not appear to use the water. The constraint to deploy the experiment within 3 days after launch was not observed because of delay in the overall scheduled Skylab activities at that time.

After verification check on Day 73, the crew described to ground control the failure of the automatic camera actuator to operate properly in the automatic mode. On Day 80, a procedure was sent up to the crew for readjusting the actuator electronics. Implementing the procedure did not resolve the problem, so the experiment was performed with the actuator in the manual mode. Since the unit was not returned, the only basis for failure analysis was the crew voice transcript. Primary power flow in the automatic mode was normal. The camera and lights were turned on at initial equipment activation, and the time-delay circuitry deenergized both camera and lighting circuit in the normal design fashion. Signal flow in the automatic mode was not complete in that the lights and camera would not come on again when the ultrasonic field was intentionally disturbed to check proper operation. The unit is complex and the failure experienced could be attributed to failure of any one of a number of electrical components or interconnections. Also, detuning of the local oscillator or a frequency shift in either of the ultrasonic transducers could account for the problem. No further action was taken to resolve the problem. The motion picture film of web formation during unattended periods was not acquired.

#### 12.5.13 Plant Growth and Plant Phototropism (ED61-62)

The plant growth experiment (ED61) determines the effect of zero gravity on rice seed root and stem growth. The plant phototropism experiment (ED62) determines whether light can be used as a substitute in causing rice seed root and stem growth in the appropriate direction in zero gravity, and investigates the minimum light level required.

The experiment equipment consists of an 8-compartment seed container with agar and a seed planter with 24 rice seeds, as shown in figure 12-63. Experiment support hardware includes a 35-millimeter still camera with film supply and a light meter. Six of the seed container compartments have windows of varying neutral density to admit light, and two compartments have no windows. All have a second transparent window that is opened only for photography.

It is required that, periodically, over 12 days, eight photographic sessions be conducted in which pairs of compartments are photographed from the top and from the side for eight photographs per session. Illumination at the light-admitting windows of the seed container is to be at least 30 foot-candles. The seed planter

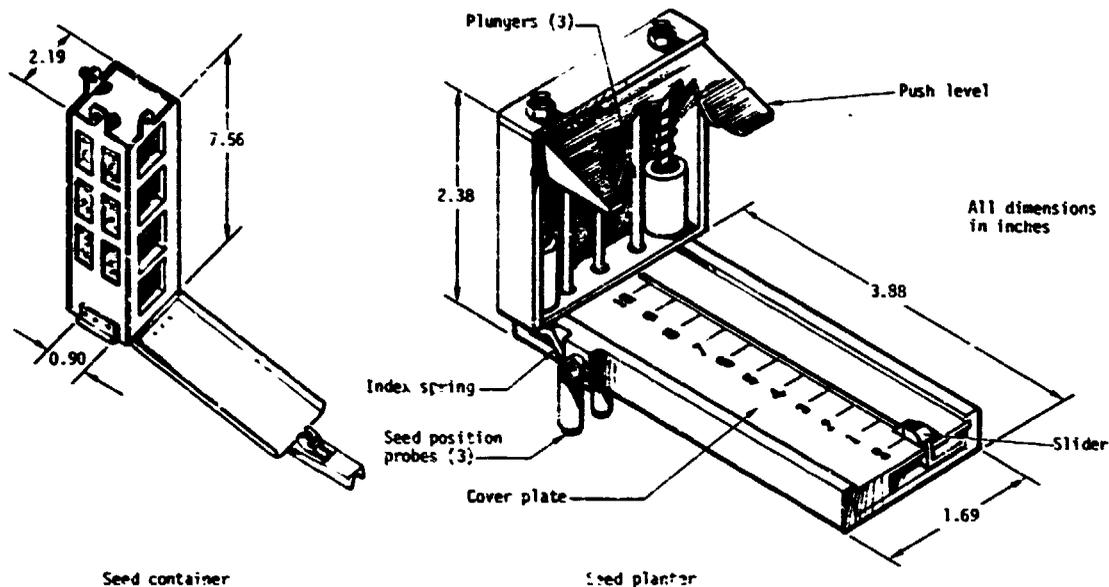


Figure 12-63.- Seed container and planter.

must be disposed of immediately after seed implantation. The seed planter and container are removed from stowage and transferred to the workshop wardroom. Three seeds are planted in each of the eight compartments. The container is mounted in the plant growth location opposite the designated illumination source, and the illumination falling on the container windows is measured. Observations and photographic sessions are conducted periodically as required.

On Day 237, the seeds were planted in all compartments except in compartment 2, and the container was installed in the wardroom. Illumination measured 5 to 20 foot-candles. The container was discovered after the mission to have been shifted somewhat from its correct location. Photography was performed 2, 3, 4, 5, 6, 8, 12, 16, and 22 days after seed planting. The glass cover plates and filters were removed on Day 262 to expose the plant to ambient atmosphere.

The required photographic data and crew voice commentary were obtained. All other requirements were satisfied except that the illumination was low and photography was not obtained as required on the 10th day. Three functional discrepancies were experienced. The seed container was incorrectly positioned and low light levels resulted. Also, seed implantation of compartment 2 did not occur. These two problems were attributed to inadequacies in crew check lists and training. The third problem was that the original seed planter had to be replaced because of the abnormally high temperatures experienced in the Saturn Workshop before the first manned period.

#### 12.5.14 Cytoplasmic Streaming (ED63)

The cytoplasmic streaming experiment (ED63) observes the effects of zero gravity on intercellular cytoplasmic streaming in the aquatic plant, elodea. The experiment equipment consists of three vials containing elodea sprigs suspended in a nutrient agar solution, a set of microscopic slides and cover slips, and a pair of tweezers, all packaged in a container. Experiment support hardware includes a microscope, microscope camera adapter, microscope mirror assembly, and a 16-millimeter motion picture camera with film supply.

It is required that the elodea vials be transferred to an area with an illumination level of at least 20 foot-candles within 3 days after launch. Photography of microscopic images at 400:1 magnification is to be conducted between 5 to 7, 12 to 15, and 21 to 25 days after launch. Fifty feet of motion picture film at 6 frames per second are to be acquired. The elodea vials are deployed in the workshop wardroom, and the ambient illumination is measured. Three times during the mission, wet slides of plant leaves are prepared for microscopic examination and photography.

The plant vials were deployed during the second manned period on Day 79, after 8 days of darkness. In the first observation, on Day 90, of a slide prepared from the healthiest appearing plant, no streaming could be observed. The experiment was rescheduled for the third manned period, and the plant vials were packaged in transparent containers to keep them alive by permitting the impingement of all available light. Exposure to direct sunlight occurred during transport in the command and service module. In the first observation during the third manned period, streaming could be observed in the specimen prepared from the one plant remaining viable. In the second observation no streaming could be detected.

The returned data consisted of the motion picture film. Film from the second manned period was underexposed and unusable because the microscope had not been adjusted to provide adequate light for photography. Portions of the film from the third manned period were acceptable though no streaming was photographed. Some of the film was shot with the microscope eyepiece inadvertently omitted, resulting in too little magnification. Some soft focus was noted, possibly caused by an improperly made slide.

The elodea plants died during both experiment attempts. In the first attempt, ground support personnel had anticipated the problem when the storage period went past 6 days of darkness and had sent the crew a test for plant viability. Ground testing revealed that plant viability became marginal after 8 days of darkness. In the second attempt, plant death was possibly caused by the direct exposure to sunlight after transparent storage containers had been provided to prevent repetition of the first failure.

#### 12.5.15 Capillary Study (ED72)

The capillary study experiment (ED72) determines the effect of zero gravity on the characteristics of wicking and capillary attraction. The experiment hardware consists of two capillary tube modules and a capillary wick module. Each capillary tube module contains identical sets of three tubes of graduated sizes. Each module has a fluid reservoir, one containing water and the other oil. The capillary wick module contains three capillaries of twill and mesh screen with a reservoir of water. The mouths of the capillary devices are maintained in contact with the reservoir fluid, but capillary action is inhibited by a lever-controlled valve until experiment activation. The experiment support hardware includes a 16-millimeter motion picture camera with film and a portable timer. It is required that thruster firings and control gyro desaturation maneuvers be inhibited during experiment operation. Up to 100 feet of film data of the operational sequence are to be acquired.

The three capillary modules are deployed on the workshop wardroom worktable. The camera is installed on the mount, and the portable timer is positioned so that the readout is in the camera's field of view. The screen wicking assembly is activated first. Time and motion picture data are obtained during wicking action. A maximum of 11 minutes is allocated. The same performance sequence is employed

for the water and oil capillary tube modules with maximum time allocations of 30 seconds for the water and 16.5 minutes for the oil.

Operation of the experiment wicking modules was initiated on Day 225. Little or no wicking action was observed over an extended observation period of 2.5 hours. The wicking module was then moved and a complete wicking action thereby initiated, although no film data were obtained. On Day 242, the capillary tube modules were activated, but no capillary action occurred. The returned data consisted of a small amount of film showing the very little initial wicking that occurred and a sketch by a crewman of the wicking observed after 27 minutes, after 1 hour 47 minutes, and after 2 hours 44 minutes following activation.

Wicking and capillary action failed to occur when the modules were activated. Inspection of the stowage area by the crew revealed evidence of fluid leakage. A procedure to refill the reservoirs was sent up, but the crew had discarded the modules. The hardware was not returned for analysis, so the cause of leakage can only be hypothesized. Some leakage problems were experienced during hardware development. Several possible locations and causes for the leakage were postulated, however, no specific cause can be identified except the abnormal combinations of temperature and pressure.

#### 12.5.16 Mass Measurement (ED74)

The mass measurement experiment (ED74) demonstrates the measurement of mass in zero gravity and how the laws governing simple harmonic motion are applied in the Skylab specimen mass and body mass measurement devices. The experiment hardware consists of a cantilevered spring

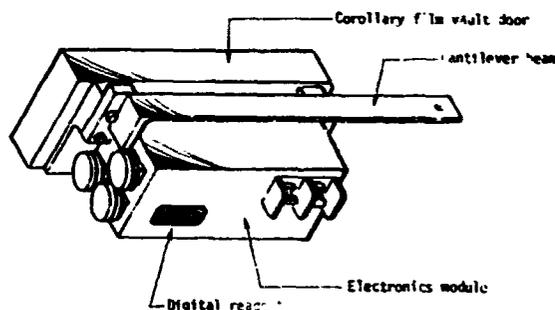


Figure 12-64.- Mass measurement device.

beam firmly attached to a frequency counter (fig. 12-64), six weights, and a data table. A means is provided for attaching the weights to the free end of the beam. A strain gage senses beam oscillation and provides a signal to the frequency counter which has a visible readout of the period in seconds. The data table correlates period measurements to mass as calculated using the beam spring constant measured on Earth. The experiment support hardware includes a 16-millimeter motion picture camera and film supply. The experiment requires four mass measurements using up

to six masses, and one measurement using only the calibration mass. It requires photographic coverage of each measurement at 24 frames per second for 50 oscillations after initial beam deflection. Mass measurements are not to be performed during Skylab attitude maneuvering.

The experiment hardware is bolted to the workshop film vault for operation. Motion picture film is obtained of beam deflection and oscillation for each mass measurement of the weights affixed to the beam. The camera is pointed to include the counter display in the field of view. The experiment was performed on Day 106. Five mass measurements were made and the required motion picture photography performed. All experiment requirements and constraints were satisfied. Period data returned over the voice link are shown together with premission calculated period data in table 12-V. Performance of the experiment was as expected. The 3 to 4 percent difference between calculated and flight-measured data is attributed to inexact knowledge of the beam's physical properties. The returned data also included 90 feet of motion picture film.

## 12.5.17 Neutron Analysis (ED76)

The neutron analysis experiment (ED76) measures the ambient neutron flux and determines the relative sources of this flux from high energy solar neutrons, Earth albedo neutrons, and cosmic ray secondary neutrons.

Table 12-V.- Mass Measurement Data  
Table 12-V.- Mass Measurement Data

Leading, number of weights	Mass, grams	Calculated period, second	Measured period, second
System +1	197.6	0.59	0.57
System +2	300.1	0.72	0.69
System +3	402.6	0.83	0.80
System +4	505.1	0.93	0.89
System +5	607.5	1.01	0.98

with it is a recording layer of solid dielectric material. An aluminum slide separating the paneled layer from the recording medium is removed when the detector is activated. When the foil elements undergo fission caused by neutron impingement, they emit charged fission fragments. Similarly, the boron is activated by neutron radiation and undergoes radioactive decay, emitting alpha particles.

These emissions produce damaged polymer chains in the crystal structure of the dielectric recording layer. The damage paths are subsequently etched out chemically, and the particle path is observed under the microscope. The detectors must be deployed throughout the Skylab interior within 5 days after launch and remain a minimum of 18 days. Four are returned at the end of the first manned period and the remainder at the end of the third manned period. The detectors are deployed throughout the forward compartment and dome areas of the workshop. The aluminum slide is removed from each detector to activate it.

The detectors were deployed on Day 18. Four were deactivated for return on Day 38. The remainder were deactivated for return on Day 264. Preliminary data analysis performed on the four detectors returned after the first manned period indicated that the observed track densities were significantly greater than predicted. As a result, an 11th detector was launched and deployed in the command and service module during the third manned period.

The returned data were the 11 detectors. There were indications that the tracks in the high energy bismuth and thorium recording media may have been biased by proton induced fission. The detector located in the command and service module provided better data for modifying the Skylab neutron flux sources, since this location is least affected by the Saturn Workshop water tanks.

## 12.5.18 Liquid Motion in Zero Gravity (ED78)

The liquid motion in zero gravity experiment (ED78) examines the dynamic response of a liquid and gas interface in a zero gravity environment when subjected to a pseudo-impulse. The experiment hardware is a liquid motion module having two sections, as shown conceptually in figure 12-66. One section is a gas and liquid chamber with a viewing port for photographic purposes. It contains a

The experiment hardware consists of 10 neutron detectors (fig. 12-65) with carrying cases. Each neutron detector consists of a layer having panels of bismuth, thorium, uranium, cadmium covered U-235, and B-10 fissionable foils. A boron panel is also included. Parallel to the layer of panels and in intimate contact

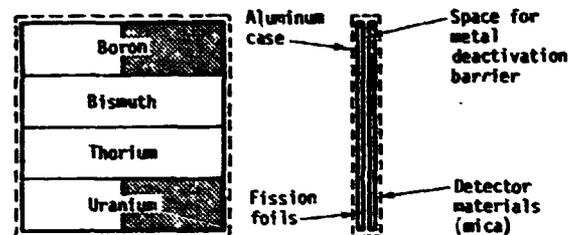


Figure 12-65.- Neutron detector.

liquid working agent mixed with dye in which an air bubble is inserted. The chamber is sealed by a flexible diaphragm at a pressure of one atmosphere. The other section contains a piston and a piston retention and release mechanism. The piston maintains pressure on the diaphragm until it is released in the Skylab



Figure 12-66.- Liquid motion module functional diagram.

5-psia atmosphere, imparting an impulse to the liquid and gas interface. Experiment support hardware includes a 16-millimeter motion picture camera with a film supply and a camera mounting bracket.

It is required to obtain up to 100 feet of motion picture film at 24 frames per second of the liquid and gas interface when subjected to the impulse. Skylab

attitude maneuvers are not to be performed during the experiment. An attempt was made to perform the experiment on Day 111. The crew reported that although the necessary photography was accomplished, no impulse was observed when the piston was released. The crewman commented that the pressure on the gas and liquid appeared to have been previously released. It was concluded that a hardware failure had occurred that would preclude completion of the experiment, so no further experiment activities were scheduled.

None of the returned data supported the experiment objectives. No violation of the constraints was detected. The piston failed to impart an impulse to the liquid and gas interface. The crewman attempted to reset the piston and reestablish the pressure differential without success. He could then observe that the diaphragm was damaged. Fluid loss was not evident nor could change in size of the gas bubble be detected. The hardware was not returned for analysis. It can be hypothesized that the low internal Skylab pressure and elevated temperature experienced before the first manned period could have caused an excessive differential pressure across the diaphragm resulting in its eventual rupture. It has been proposed that fluid mechanics data pertinent to this experiment from the water drop science demonstration be furnished to the student investigator.

#### 12.5.19 Microorganisms in Varying Gravity (ED33)

The microorganisms in varying gravity experiment (ED33) determines the effects of varying gravity levels upon certain organisms' growth rate, development process, and ability to survive. The investigation uses a centrifuge to subject specimens to a carefully controlled regime of acceleration-time profiles. The experiment is incompatible with Skylab because of the excessive volume, electrical power, hardware complexity, and crew time required for implementation. An alternate arrangement was made to provide the student investigator with data from the Skylab Environmental Microbiology Detailed Test Objective for study. This activity requires the acquisition and return of 30 hardware, 12 crew body, and 2 atmospheric microbiological samples.

#### 12.5.20 Chick Embryology (ED51)

The chick embryology experiment (ED51) studies the embryological development of chick eggs incubated in zero gravity, and compares the motor coordination and vestibular function of a space chick with an Earth chick. Fertile eggs are launched and incubated in the workshop incubator. Development is terminated at specific times and the eggs returned. In one case, a chick is hatched and its behavior observed and photographed before its return. The experiment is incompatible with Skylab because of its excessive launch volume and hardware complexity.

An arrangement was provided for the student investigator to study the data from the circadian rhythm, pocket mice, experiment (S071).

#### 12.5.21 Brownian Motion (ED75)

The Brownian motion experiment (ED75) is a qualitative evaluation of the effects of a zero gravity environment on Brownian motion. A crystal of copper sulphate is slowly immersed in a constant temperature liquid, held in place, and allowed to dissolve. Periodic photographs are made of the dissolving salt crystal. Skylab is unable to provide the absolutely stable operating site for the time periods up to 1 month that the experiment requires. An arrangement was provided for the student investigator to study data from the stellar astronomy experiment (S019).

#### 12.5.22 Universal Gravity (ED77)

The universal gravity experiment (ED77) determines the universal gravitation constant in a null-gravity environment. A portable Cavendish balance is installed in Skylab, and the motion of the calibrated spheres is measured as a function of time. The experiment is incompatible with Skylab in that accelerations from the Skylab control mode operations greatly exceed the expected accelerations of the Cavendish balance spheres. An arrangement was provided for the student investigator to study data from the crew vehicle disturbance experiment (T013).

### 12.6 SCIENCE DEMONSTRATIONS

The science demonstrations were developed for Skylab to demonstrate scientific principles suitable for educational programming. A hardware kit for 13 demonstrations was launched for the second manned period. These demonstrations, devised at Johnson Space Center and not discussed herein, are shown in table 12-VI.

Table 12-VI.- Science Demonstrations Launched with the Second Crew

SD1	Gravity gradient effects
SD2	Magnetic torque
SD4	Momentum effects
SD5	Energy loss and angular momentum
SD6	Bead chain
SD7	Wave transmission reflection
SD8	Wilberforce pendulum
SD9	Water drop
SD10	Fish otolith
SD11	Electrostatic effects
SD12	Magnetic effects
SD13	Magnetic electrostatic effects
SD14	Airplane

During the midportion of the second manned period, the crew requested more activities as they were accomplishing scientific activities in less than the time allocated. Marshall Space Flight Center developed the diffusion in liquids (SD15) and ice melting (SD16) science demonstrations to use onboard hardware and provided the crew with operating procedures. These demonstrations were performed and are discussed in this report with the other 15 demonstrations prepared by Marshall Space Flight Center that were planned for the third manned period. Of those prepared for the third manned period, all except the gyroscope (SD28) and orbital mechanics (SD30) demonstrations were intended to provide scientific data. The

data were returned through the Skylab television, film camera, and audio systems. In some cases, material samples were brought back to Earth by the crew.

The science demonstration procedures included an addendum for the television operations book, and the assigned television designation numbers are included with the science demonstration number.

### 12.6.1 Fluid Mechanics Series (SD9-TV107)

The fluid mechanics series demonstration (SD9) is used to investigate the behavior of fluids in low gravity. The demonstration instructs the crew to perform a series of experiments with free floating fluids and fluids attached to surfaces. Oscillation damping times, surface wetting characteristics, droplet impact and coalescence, vortex formation and damping, and rotation of free floating fluid globules are recorded by the crew. All hardware for the demonstration except a blow tube was already onboard Skylab. The crew used syringes, thread, soap, various coloring agents, wire, cans, and other operational equipment, including the spider experiment cage, at their discretion.

Television recordings of this demonstration were made on Days 237, 254, and 258. The first day's demonstration included oscillations in free floating water globules, impact coalescence, globule rotation, and formation of internal vortices in the globule. Also, the newly invented zero gravity drinking cup was demonstrated, and the first drink from an open cup in zero gravity was taken. For the second performance, the crew demonstrated oscillations with the globule on a thread, by squeezing the globule with nonwetting tools and suddenly releasing it. The recorded television data showed that squeezing and suddenly releasing the globule was more effective in demonstrating oscillation than the planned procedure of simultaneously removing syringe needles from the globule. Further oscillatory motions were demonstrated with air and then with soap injected into the globule. For the last performance, the crewman used two cans with three threads stretched between them. He placed the globule on the strings and rotated the globule until it separated. He then maneuvered the globules into a collision to observe coalescence. Coalescence did not always occur; sometimes the globules collided and bounced apart.

The hardware associated with this demonstration performed well. The data acquisition camera could not be used to obtain motion pictures because it jammed; however, approximately 2 hours of excellent television recording was made.

### 12.6.2 Diffusion in Liquids (SD15-TV115)

The diffusion in liquids demonstration (SD15) is used to obtain low gravity data on mass diffusion and to demonstrate the slowness of molecular diffusion in the absence of convective mixing. Tea is prepared and injected into the fiber wad portion of a discarded forceps container cap. The transparent container is then filled with water. The tea and water are brought together into an interface without residual motions. The diffusion of the dark tea into the water is recorded by the 16-millimeter motion picture camera, with the portable timer in the field of view.

The demonstration was performed four times on Day 241. The first three attempts were unsuccessful in achieving the desired liquid interface; however, the fourth attempt succeeded. The following day, the crew reported on at least three occasions that no diffusion had occurred. The crew was instructed to begin the demonstration again. In the fifth and final setup, an interface was formed without mechanical disturbance. Diffusion was photographed, a few frames at a time, over a 3-day period. Diffusion occurred, taking an unexpected bullet shape with little or no diffusion occurring along the walls of the transparent container. The returned data were the 16-millimeter film with voice transcripts providing background information and a description of setup problems. Film images were out of focus because of a procedural error, and viewing was difficult but not impossible.

### 12.6.3 Ice Melting (SD16-TV111)

The ice melting demonstration (SD16) is used to observe the temporal progression of the liquid-solid interface in a melting material and to obtain data for thermal analysis of zero-gravity melting. The surface tension effects demonstration is used to observe changes in the shape of a spherical water globule when soap is added to one side to lower the surface tension on that side. Water is frozen in a large plastic pill dispenser and its melting is photographed. A timer and scale are placed in the camera's field of view to permit postflight determination of the melting rate and quantitative evaluation of the changing liquid-solid interface. The weight of the ice cube and container is determined and a small piece of paper is stuck to the ice surface to permit observation of fluid motion as the ice melts. During the surface tension effects demonstration, liquid shower soap is used to change the surface tension of the water globule. A 5 cm<sup>3</sup> syringe is used to inject grapejuice and air into the water globule.

The ice was removed from the container using a dry swab that had been frozen in to facilitate handling. The ice cylinder was then attached to tape while the melting process was observed. Photographs were taken at 5-minute intervals throughout the approximately 3 hours required to melt the ice. Liquid shower soap was then applied to the side of the resultant water globule. However, the soap spread so rapidly over the surface of the globule that no shape change was detected. A few drops of grapejuice were added with no apparent change to the globule. The crew then elected to inject air into the globule, and discovered that small, relatively uniformly sized bubbles were formed. As air was injected more bubbles formed until the globule was full of little bubbles. As more air was injected individual little bubbles broke through the surface, sending little bits of the liquid into the workshop environment.

The 16-millimeter film was returned from this demonstration. Development of the film revealed that the images were out of focus. Voice transcripts and the postflight crew comments provided valuable descriptive information, particularly for the surface tension effects demonstration.

### 12.6.4 Ice Formation (SD17-TV112)

The ice formation demonstration (SD17) is used to observe the freezing characteristics of containerless water and aqueous solution globules. Specific interest is to observe the distribution of bubbles formed when dissolved gases come out of solution, the segregation of solute, the effects of expansion, the time of freezing, and the freezing of a water droplet on a sphere of ice. This demonstration uses hardware already onboard Skylab. Two globules of water are suspended on a string attached inside a corner of a food freezer. One globule is clear water and the other is dyed with an onboard solute. The globules are observed and photographed during freezing. After they have frozen, a small drop of water is placed on one of the ice spheres, and the behavior of the drop observed and photographed. Returned data were to be 35-millimeter photographs. The demonstration, however, was not performed because of the lack of crew time.

### 12.6.5 Effervescence (SD18-TV113)

The effervescence demonstration (SD18) is used to observe bubble formation in an effervescent reaction in low gravity. Another objective, related to zero gravity flammability studies, is to determine whether or not the reaction is

self-quenching as the bubble grows. A transparent container, selected by the crew, is filled with water, an effervescing tablet is inserted, and the reaction is observed. This demonstration was not performed because of insufficient crew time.

#### 12.6.6 Immiscible Liquids (SD19-TV102)

The immiscible liquids demonstration (SD19) is used to examine the behavior of immiscible liquids in zero gravity and to determine the time of coalescence. Three identical, transparent vials are provided, each containing different proportions of clear oil and colored water. The proportions are 25, 50, and 75 percent Krytox 143 AZ oil, with the remaining volume filled with water. A small brass nut is included in each vial to stir the liquids when shaken in zero gravity. The vials are assembled in a frame so that they can be either shaken, centrifuged, or photographed simultaneously. Hand-held photography using a 35-millimeter still camera with an extension tube is performed over a 24-hour period after agitation of the vials.

The demonstration was performed on Day 235. The liquids were separated by centrifugal motion and then shaken to initiate mixing. The frame of vials was mounted and long term coalescence photography was started. Three photographs were taken at 30-second intervals, five at 2-minute intervals, and one photograph after 1, 2, 5, and 10 hours. Photography was terminated at that time because of a time conflict in the use of the 35-millimeter camera. Beyond the normal video, returned data were the 35-millimeter photographs and verbal comments. The photographs were poor, possibly because of lighting or focusing problems, but some useful data may be extracted using densitometric scanning techniques.

#### 12.6.7 Liquid Floating Zone (SD20-TV101)

The liquid floating zone demonstration (SD20) is used to examine the stability of a liquid zone surface in low gravity under rotating conditions and axial accelerations and to investigate the fluid dynamics of the liquid zone interior under rotating conditions. The demonstration is performed by placing a water globule of measured zone size between two circular wetting surfaces that can be rotated about a common axis normal to the surfaces. The surfaces can be rotated singly or simultaneously, in the same direction or in opposite directions, and at various rotational velocities. The demonstration setup is arranged using onboard universal mounts and socket set extensions with items from the science demonstration kit. Rope particles, tea, grapejuice, and strawberry drink are used to provide visual tracers in the liquid so that internal fluid motion can be observed.

The crew began the demonstration on Day 243 and performed 26 runs until the conclusion on Day 247. The demonstration was set up as expected except that some undesirable wetting of the disk edges occurred. This was controlled by application of Krytox grease to the edges. Video data were satisfactory except that procedural oversights in the television system operation resulted in the loss of video data for six runs. The instability of the liquid zones at increased rotational velocities was generally manifested by the entire zone's taking on a "jump rope" shape that swung around the axis of rotation. The effect of artificial gravity created by centrifugal force in the rotating liquid zone was observed on ice and air bubbles. These bubbles moved toward the axis of rotation.

#### 12.6.8 Deposition of Silver Crystals (SD21-TV106)

The deposition of silver crystals demonstration (SD21) shows crystal growth by chemical reaction in low gravity to compare crystals grown in low gravity with those grown in normal Earth gravity. The crewman places copper wire, with breaks in the coating to provide reaction sites, in a dilute silver nitrate solution and observes silver crystal growth. Photographs are taken at intervals of approximately 6, 24, and 72 hours to encompass the anticipated crystal growth period.

Approximately 10 hours after initiation of the demonstration, the first two photographs of the crystals were taken with a 35-millimeter Nikon camera with the 55-millimeter lens and K-1 adapter. At approximately 24 hours into the crystal growth cycle, a second set of two photographs was taken. The final set of three photographs was taken approximately 72 hours after initiation. The crew commented that the greatest growth rate was in the first 24 hours, with maximum growth reached between 24 and 48 hours.

The returned crystals were the principal data from this demonstration; however, the vial was dropped while being unwrapped and the silver crystals were broken off of the wire. Supplemental data were to be derived from photographs and the crew's description, but the 35-millimeter magazine which contained all of the photographs was blank. The reason for the blank film has not been established. Some of the individual crystals from the vial may be recoverable; however, the crew comments and descriptions provide the only record of their appearance and distribution on the wire.

#### 12.6.9 Liquid Films (SD22-TV103)

The liquid films demonstration (SD22) consists of forming liquid films in zero gravity and observing their lifetime. A crewman, using a syringe, forms liquid films by injecting a water or soap and water globule into expandable, two-dimensional, wire frames. He then expands the frames to form films of differing area size. The crewman also forms films by immersing three-dimensional, cube or tetrahedron, wire frames in a container of the liquid. He withdraws and shakes the frames to remove excess liquid until separate films are formed in each of the frames. The lifetime of the films is observed.

The demonstration was performed on Day 256. Using water, the crewman could expand the two-dimensional frame to 1.5 to 2 inches in diameter. Using a 40:1 soap and water solution, he could obtain 6- to 6.5-inch diameters. With the three-dimensional frames, it was best to remove the frame from the liquid slowly. It proved difficult to remove all of the center globules of liquid and still retain a film to each of the sides. The three-dimensional frames produced films that were relatively short-lived. The crew reported a maximum film lifetime of 1 minute with the cube frame. The video data were of fair quality and could perhaps have been improved by better lighting and use of the accessory closeup lens on the television camera.

#### 12.6.10 Lens Formation (SD23-TV116)

The lens formation demonstration (SD23) is used to observe formation of lenses shaped by surface tension under zero gravity conditions and to obtain preliminary data on the optical properties of lenses formed by surface tension. The crewman forms maximum and minimum sized wafer lenses on a wire loop and records their shapes with edge-view photographs using a 35-millimeter still

camera. He takes photographs through the lenses to determine focal lengths and other optical properties. Lenses are also formed from a soap solution during this portion of the demonstration. In addition, the crewman examines the optical properties of a wafer prism defined by a bent wire shape. Finally, the crewman, by allowing melted soap to cool on the wire frame, forms a soap lens for return and postmission examination. The demonstration was not performed because of insufficient crew time.

#### 12.6.11 Acoustic Positioning (SD24-TV114)

The acoustic positioning demonstration (SD24) tests the use of a combination of radiated and reflected sound pressure waves to position and control the motion of small particles in zero gravity. Two tones of 2 and 3 kilohertz were prerecorded on a cassette for 5 minutes each on the ground and sent with the third crew. The crew builds a suitable reflector using miscellaneous material onboard Skylab. The cassette is played aboard Skylab and the reflector positioned to produce a standing wave. Small drops of water are released near the reflector. The drops are expected to move to an antinodal point where they may coalesce into a larger globule. Returned data are television recordings and crew comments. The demonstration was not performed, however, because of the lack of crew time.

#### 12.6.12 Gyroscope (SD28-TV104)

The gyroscope demonstration (SD28) is used to show the behavior of a gyroscope in zero gravity. The gyroscope is a standard toy version modified to suit the objectives and to meet materials and safety requirements. The gyroscope wheel is spun up and various forces are applied to it to show translation and rotational effects.

The crewman showed the unstable motion of a nonspinning gyroscope, demonstrating that after a force was applied the gyroscope translated and tumbled. He then spun-up the gyroscope and showed that the gyroscope translated after a force was applied, but that it did not tumble or drift in rotation, and it rotated only while the torque was applied. Precession at three wheel speeds was also demonstrated. First, at high speed the gyroscope precessed at approximately 90 degrees from the direction of the applied forces, with little wobble introduced. At an intermediate wheel speed, a little more wobble was introduced. At very slow speed, the resultant precession was about 20 degrees from the theoretical 90 degrees. The returned data were the video recording and the accompanying voice recordings. Both were of excellent quality.

#### 12.6.13 Cloud Formation (SD29-TV118)

The cloud formation demonstration (SD29) is used to investigate the lifetime history and dynamics of an expansion cloud in zero gravity. Cabin atmosphere is compressed in a closed transparent chamber, and, after the gas reaches thermal equilibrium, the gas is expanded and the formation, motion, coalescence, and lifetime of the water droplets (cloud) are observed. The demonstration is photographed with the 16-millimeter data acquisition camera and, at crew option, is recorded with the television system.

The crew tried many times to make a cloud form in the chamber, but the results were negative. Droplets formed on the chamber walls, but a cloud in the gas was never visible. Supersaturation of the gas and a wide range of compression

hold times were tried without success. Since a cloud was never observed, photographs and applicable crew comments were never made.

#### 12.6.14 Orbital Mechanics (SD30-TV110)

The orbital mechanics demonstration (SD30) demonstrates some of the principles of orbital mechanics. A crewman suspends three balls inside the workshop "in mid-air" without support. The balls are monitored by television while Skylab is accelerated during a trim burn.

The demonstration was performed on Day 253. Before the demonstration, the crewman pointed out the reason for the trim burn and explained how he had seen items move inside the workshop during previous trim burns. The balls were suspended in front of a television camera. When the maneuver began, the balls moved quickly out of the camera's field of view while the crewman described the demonstration: ". . . the balls are floating freely but they appear to move relative to the workshop because the workshop is moving." Returned data from the demonstration were the video recording and the accompanying voice recording. These were of good quality and should be usable as educational material.

#### 12.6.15 Rochelle Salt Growth (SD33-TV105)

In the Rochelle salt growth demonstration (SD33) Rochelle salt crystals are grown by precipitation from a saturated solution in zero gravity. The Rochelle salt (sodium potassium tartrate) consists of a 26-gram seed crystal plus enough sacrificial crystals to maintain a saturated solution up to 71°C. The solution is placed in large Skylab food cans with transparent tops and is heated to approximately 65°C. As the mixture is allowed to cool slowly, additional material precipitates on the seed crystal.

After heating the solution and allowing time for gradual cooldown, the crew reported that a satisfactory crystal had formed. The flat, layered crystal was photographed, removed from the can, wrapped in a facecloth, and returned for analysis of the ferroelectric hysteresis characteristics to determine the quality of the crystal. Reflection and poor visibility of a clear crystal in a white can prevented adequate photography and video recordings of the crystal. The crew's description of the crystal was highly valuable, particularly in view of the inability to photograph the freshly grown crystal, and indicated that the crystal dissolved somewhat during the 30 days that it remained in the solution after growth.

#### 12.6.16 Neutron Environment (SD34-TV108)

The neutron environment demonstration (SD34) measures the intensity and spectrum of neutrons near massive and nonmassive objects in Skylab. Five metal samples susceptible to neutron activation at various energy levels are enclosed in a cloth packet. The samples are hafnium, nickel, titanium, tantalum, and cadmium-covered tantalum. The samples are approximately 2 centimeters square by 0.32 centimeter thick, except for the cadmium-covered tantalum, which is somewhat larger because it is encapsulated to prevent the cadmium from outgassing. Four packets are deployed near massive and nonmassive objects aboard Skylab. The neutron flux is determined by postflight analysis of the returned samples. The results of the gamma ray analysis will be combined with the known activation cross-sections of the sample materials. From this, the time-integrated neutron environment at each sample's location aboard Skylab can be determined.

The four packets were deployed on Day 191. The two deployed near massive objects were taped to a film vault drawer and a water tank. The two deployed near nonmassive objects were taped to the workshop walls in the sleep compartment and forward dome. Photographs of the deployed packets were made to record the installation location. The packets were deployed for 76 days; then they were taken down for return to Earth.

#### 12.6.17 Charged Particle Mobility (SD35-TV117)

The charged particle mobility demonstration (SD35) observes and photographs separation of sedimenting and nonsedimenting particles in solution under the influence of an electric field in a low gravity environment. A potential of 28 vdc is applied across each of two fluid columns, one of red blood cells and the other of protein, and the migration of the particles is observed. The potential is reversed, and the migration of particles in the opposite direction is observed. The specimens are contained in a charged particle mobility device consisting of two cells, each with reservoirs at the ends of a sample tube. A manually operated gate valve is located at the entrance to each tube. Electrodes are immersed in the fluid at each end of the tube. Cell 1 contains human blood and cell 2 contains two proteins. The tube for each cell contains two buffer solutions to produce a uniform diffusion front when the cell is operated. Electric power is obtained from the laboratory power system.

Special equipment for the demonstration was launched with the third crew. The samples were to remain refrigerated but were misplaced in the transfers from the command module to the Saturn Workshop. Consequently, the samples were unrefrigerated for 2 weeks. The demonstration was performed on Day 207. The red blood cell sample demonstration was performed first and was subsequently repeated after the second sample demonstration was performed. The first run was performed without having removed the bubbles from the solution. In both demonstrations using the red blood cell sample, the cells showed movement. Nineteen 35-millimeter photographs were taken during these two demonstrations. No movement was seen within the protein sample. Eight 35-millimeter photographs were taken while it was being performed, even though the crewman could not observe any migration within.

The demonstration hardware performed as expected. Twenty-seven 35-millimeter photographs of the demonstration performance were returned along with the recorded crew comments. The lack of refrigeration of the sample for almost 2 weeks adversely affected the results of the demonstration. The red blood cells may have been destroyed, so the data on these were degraded. The two proteins had probably broken down, so no meaningful data were obtained from that sample.

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SKYLAB MISSION REPORT - SATURN WORKSHOP

By

Skylab Mission Evaluation Working Group

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

  
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